Author:
Mattocks, Calum Gallagher

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THE USE OF ACCELEROMETERS TO ASSESS PHYSICAL ACTIVITY AND EXPLORE POTENTIAL EARLY LIFE DETERMINANTS IN A LARGE COHORT OF CHILDREN

Calum Gallagher Mattocks

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Abstract

Background
There is increasing evidence that low levels of physical activity may contribute to a range of poor health outcomes in children. Knowledge of the factors that might influence physical activity can inform the design of intervention studies and, ultimately, public health policy.

Aims
The aims of this thesis were to investigate and validate the measurement of physical activity in Avon Longitudinal Study of Parents and Children (ALSPAC) using the Actigraph accelerometer and to examine the early life (0-5 years) determinants of physical activity in ALSPAC among 11-12 year olds.

Methods
Children were asked to wear an Actigraph accelerometer for seven days at the ALSPAC 11-year clinic visit. Early life data were collected from the time the mother was pregnant until the child was aged five. Analyses were undertaken to identify early life determinants of physical activity at age 11-12.

Results
A total of 11,952 children were invited to come to the 11-year clinic, of whom 7,159 (60%) came for assessment and 6,622 (93% of those who attended) agreed to wear an Actigraph. Valid Actigraph data, defined as at least three days of physical activity for at least 10 hours a day gave a reliability of 0.7. Data were available for 5451 (82% of those who agreed to wear an Actigraph) children for the Determinants study. Maternal swimming and brisk walking during pregnancy and parents' physical activity when the child was aged 21 months were positively associated with physical activity at age 11-12.

Conclusions
The Actigraph was successfully incorporated into a large, established cohort-ALSPAC. Parents' physical activity during pregnancy and early in the child's life showed a modest association with physical activity of the child at age 11-12 years, suggesting that active parents tend to raise active children. Helping parents to increase their physical activity therefore may promote children's activity.

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I would also like to thank all those other people involved in the data collection: the reception and nutrition teams, data collectors, administration, computing, PR and family liaison teams and the post room, without whom ALSPAC would cease to function.

Finally, thanks must go to the children and families of ALSPAC who give up their time to provide us with valuable data to analyse.

Author's declaration

I declare that the work in this dissertation was carried out in accordance with the regulations of the University of Bristol. The work is original, except where indicated in the text, and no part of this dissertation has been submitted for any other academic award.

The Avon Longitudinal Study of Parents and Children (ALSPAC) is an ongoing project based in Bristol that started in 1991. Within ALSPAC, I carried out the physical activity study that forms the basis of this thesis. I reviewed the literature, collaborated in the design of the main study and sub-studies, managed the study team, collected the data, assisted in cleaning the data with Dr Sam Leary, performed all data analyses in Chapters 10 and 11 with the assistance of Drs. Sam Leary, Andy Ness and Kate Tilling, and assisted Dr Sam Leary with the data analyses in Chapters 8 and 9.

Name......CALUM MATTOCKS..................

Signed....Calum Mattocks...............................

Date.........24/7/09..

Glossary and abbreviations

Accelerometer – a device used to measure physical activity by using the acceleration of movement

ALSPAC – Avon Longitudinal Study of Parents and Children

ANOVA – analysis of variance

BMC – bone mineral content

BMD – bone mineral density

BMI – body mass index

CI – confidence interval

CiF – Children in Focus

CHD – coronary heart disease

COPD – chronic obstructive pulmonary disease

ELSPAC – European Longitudinal Study of Parents and Children

HDL-C – high-density lipoprotein cholesterol

HR Flex – The point above which the relationship between heart rate and energy expenditure becomes linear

ICC – intraclass correlation coefficient

IQR – interquartile range

LDL-C – low-density lipoprotein cholesterol

MET – metabolic equivalent

MRC – Medical Research Council

MVPA – moderate to vigorous physical activity

NHANES – National Health and Nutrition Examination Survey

NHS – National Health Service

OR – odds ratio

Pedometer – a device used to measure physical activity by counting the number of steps taken

Reactivity – the phenomenon whereby subjects change their behaviour when they know they are being assessed

RR – relative risk

SD – standard deviation

SE – standard error

SMD – standardised mean difference

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Chapter 1. Structure, definitions, background, rationale and structure of thesis

1.1 Objectives of this chapter

The objectives of this chapter are to:

- Describe the structure of the thesis
- Provide a brief overview of the benefits of physical activity
- Introduce definitions pertinent to the thesis
- Rationale for the thesis
- List the objectives of the thesis

1.2 Structure of the thesis

This thesis comprises the following chapters: Chapter 1 (this chapter) is a general introductory chapter; Chapter 2 provides an overview of methods of measuring physical activity; Chapter 3 reviews the literature on the benefits of physical activity, describes levels of physical activity in different populations and trends in physical activity in different populations; Chapter 4 reviews the determinants of physical activity in different populations and describes the rationale for this research; Chapter 5 describes the Avon Longitudinal Study of Parents and Children (ALSPAC), the early life variables used and how the data were collected; Chapter 6 describes the methodology of physical activity data collection in ALSPAC, including both sub-studies; Chapter 7 describes the statistics methodology; Chapter 8 is the results chapter and includes results for all studies presented here; Chapter 9 the first of two discussion chapters discusses the results of each of the five studies individually. Finally, Chapter 10 is a broader discussion, bringing together each of the outcomes from Chapter 9 and discussing them in the context of overall findings, implications for policy and recommendations for future research.

The thesis has produced the five papers listed below. Each paper will also be referred to by a shorthand version as follows: the Methods study; the K4 study; the Four Seasons study; the Descriptives study; and the Determinants study, repectively.

- Mattocks C, Ness A, Leary S, Tilling K, Blair SN, Shield J, Deere K, Saunders J, Kirkby J, Davey Smith G *et al.*: Use of accelerometers in a large field based study of children: protocols, design issues and effects on precision. Journal of Physical Activity and Health. 5 (Suppl 1): S98-S111, 2008 [1] (the Methods study)

- Mattocks C, Ness A, Leary S, Tilling K, Deere K, Kirkby J, Saunders J, Riddoch C and Blair S: Calibration of an accelerometer during free-living activities in children. International Journal of Pediatric Obesity. 2: 218-226, 2007 [2] (the K4 study)

- Mattocks C, Leary S, Ness A, Deere K, Saunders J, Kirkby J, Blair S, Tilling K and Riddoch C: Intra-individual variation of objectively measured physical activity in children. Medicine & Science in Sport and Exercise. 39: 622-629, 2007 [3] (the Four Seasons study)

- Riddoch C, Mattocks C, Deere K, Saunders J, Kirkby J, Tilling K, Leary S, Blair S and Ness A: Objective measurement of levels and patterns of physical activity. Archives of Disease in Childhood. 92: 963-969, 2007 [4] (the Descriptives study)

- Mattocks C, Ness A, Deere K, Tilling K, Leary S, Blair SN and Riddoch C: Early life determinants of physical activity in 11-12 year olds: a cohort study. British Medical Journal. 336: 26-29, 2007 [5] (the Determinants study)

Copies of these papers are in Appendices 1 to 5.

1.3 The benefits of physical activity

Physical activity and exercise have long been recognised as being important to health [6]. Both Galen and Hippocrates recognised the health benefits of physical activity [7]. In the past 50 years, epidemiologists have provided evidence to suggest that physical activity in adult life is beneficial to health. In particular, regular physical activity is associated with reductions in morbidity and mortality from coronary heart disease [8-11], diabetes mellitus [12,13] and certain cancers [14]. Premature deaths from inactivity in England are estimated at 54,000 per year [15].In England, it has been estimated that £2 billion per year due to healthcare costs, working days lost and the costs from premature deaths is attributable to inactivity [15]. The evidence that physical activity is beneficial to health has provided the basis for guidelines recommending appropriate levels of physical activity for adults [16,17]. Guidelines have also been issued recommending that children become more physically active, although the empirical evidence supporting children's guidelines is less convincing [18]. However, there are still many unanswered questions regarding the relationship between physical activity and health. Numerous studies have found positive associations between physical activity and health outcomes but the optimum volume of physical activity to achieve and maintain health is still unclear, and may be different for different health outcomes and different populations [19]. For example, is the volume of activity needed to achieve and maintain cardiovascular health different from that needed to prevent obesity? [20] There is also the question of whether physical inactivity (sedentary behaviour) and physical activity are separate constructs rather than simply the opposite of one another. It may be possible to attain the minimum recommended amount of physical activity yet accrue long periods of sedentary behaviour [21]. The consequences of such behaviour to health are not known. These are just a few examples of the many unanswered questions regarding physical activity and health. There are many more and it is clear that there is still some way to go until the relationships between physical activity and health are fully understood.

1.4 Definitions

The definitions for physical activity, exercise, physical fitness, energy expenditure and determinant that will be used in this thesis are given in the following section.

Physical activity can include the activities necessary for work, the daily tasks of living (housework *etc.*) and leisure activities [22]. Physical activity is a complex multidimensional behaviour and as such is difficult to measure [23]. Casperson *et al.* [24] coined the most widely adopted formal definition:

> *"any bodily movement produced by skeletal muscles that results in energy expenditure"* [24]

It is useful to consider physical activity in terms of its attributes or dimensions. These are volume (the total amount of activity done), duration, frequency, intensity and mode [25].

Exercise is a subset of physical activity and has been formally defined as:

> *"planned, structured, and repetitive and has as a final or an intermediate objective the improvement or maintenance of physical fitness"* [24]

Physical fitness (referred to as "fitness" from here onwards) is defined as:

> *"A set of attributes that people have or achieve relating to their ability to perform physical activity"* [24]

These attributes can be either health or performance related but since this study is primarily concerned with health, only health-related fitness will be considered in this thesis. Health related fitness has various components. These are listed in Table 1.1.

Table 1.1 Components of health-related fitness

Morphological component	Cardiorespiratory component	Metabolic component	Motor component	Muscular component
Body mass for height	Submaximal exercise capacity	Glucose tolerance	Agility	Power
Body composition	Maximal aerobic power	Insulin sensitivity	Balance	Strength
Subcutaneous fat distribution	Heart functions	Lipid metabolism	Coordination	Endurance
Abdominal visceral fat	Lung functions	Substrate oxidation characteristics	Speed of movement	
Bone density	Blood pressure			
Flexibility				

Bouchard *et al.* [22]

Energy expenditure comprises three components which make up an individual's total energy expenditure [26]. These are shown in Table 1.2 along with the relative proportions of each component.

Table 1.2 Components of total energy expenditure

Component of total EE	Proportion of total EE
Resting metabolic rate	~ 60-75%
Thermic effect of food	~10%
Physical activity EE	~15-30%

EE- energy expenditure

Physical activity energy expenditure is the most variable of these, is amenable to modification and as such has the greater potential to impact on health.

Bauman et al [27] defined a **determinant** as a causal factor, though they point out that there are few casual factors that are both necessary and sufficient. In order to demonstrate causality, the exposure must precede the outcome (as well as meeting the other Bradford-Hill criteria [28]). As all exposures precede the outcome in this thesis, there is the potential for identifying causal relationships.

1.5 Rationale for this thesis

This thesis will document the incorporation of the Actigraph accelerometer into an existing birth cohort in order to measure physical activity. The relationship between physical activity and health in children is not fully understood and part of the reason for this has been the lack of precise and accurate methods for measuring physical activity. Instruments to measure physical activity objectively have been developed that address some of the problems with the more traditional self-report methods. The work in this thesis will report on the methods used to include the measurement of physical activity using the Actigraph into ALSPAC; how the data were interpreted; the two sub-studies that were designed to aid interpretation of Actigraph data; and how the Actigraph was used to examine the levels and patterns of physical activity and the associations between early life factors and physical activity in children aged 11-12.

Although Actigraphs have been in use for over ten years, there are still issues around the interpretation of the data. The Methods study addresses the question of how to practically incorporate the Actigraph into ALSPAC. It also deals with the issues of the number of days of measurement needed to adequately capture usual activity, compliance, statistical power of the study and bias in the sample. The two calibration studies also deal with the measurement of physical activity and interpretation of the data. The K4 study is designed to develop an equation to predict energy expenditure from Actigraph data and also to derive population-specific cut-points for the lower thresholds for moderate and vigorous activity. This is to allow interpretation of the data in terms of moderate to vigorous physical activity (MVPA). The second calibration study, the Four Seasons study, is a repeat measures study on a sub-sample of ALSPAC children. This was designed to look at the intra-individual variation in physical activity over the course of one year, which is important as physical activity is usually assessed by only one measurement.

The Methods study and the two calibration studies were carried out in order to develop the methods for data collection and interpretation so that further analyses could be conducted using data that were as accurate and precise as could practicably be achieved. Some of these further analyses are presented here as the Descriptives study and the Determinants study. The methods of data collection and interpretation developed here were also repeated in two further ALSPAC data collections so that physical activity data at three time points during childhood and adolescence will be available for future analyses.

Despite the wealth of research into the associations between physical activity and health (see Chapter 3 for a full discussion), there are many unanswered questions remaining and this is particularly true of children and adolescent health. Questions such as what is the dose –response relationship between physical activity and health outcomes; whether physical activity guidelines need to be tailored differently toward different outcomes; and whether physical activity accumulated over time in short bouts are beneficial have yet to be fully elucidated. The use of objective measures of physical activity may go some way towards answering these questions but their use in large epidemiological studies has been limited. To date, they have not been incorporated into a large existing birth cohort such as ALSPAC with its wealth of data and ability to examine the relationships between physical activity and numerous exposures and outcomes.

1.6 Objectives of this thesis

The objectives of this thesis are:

- To review the literature on various methods of assessing physical activity (Chapter 2)
- To review the literature on the health benefits of physical activity in adults and children (Chapter 3)
- To review the literature on determinants of physical activity in adults and children (Chapter 4)
- To develop an equation to predict energy expenditure from accelerometer counts in children aged 11-12 years
- To define accelerometer cut-points for moderate and vigorous physical activity intensity in children aged 11-12 years
- To assess the seasonality and variability of physical activity of children aged 11-12 years over a one-year period
- To describe levels of physical activity in children aged 11-12 years
- To identify early-life determinants of physical activity in children aged 11-12 years

Chapter 2. Measurement of physical activity

The decision to incorporate the Actigraph into ALSPAC had already been made when the author started on the project. However, in order to describe the context for the choice of physical activity measurement, this chapter will examine the advantages and disadvantages of physical activity measurement methods.

This chapter will therefore discuss the following:

- The ideal attributes of a physical activity measurement instrument
- The history of physical activity measurement
- The various methods of measuring physical activity
- Future methods of physical activity measurement

2.1 The ideal instrument?

Since physical activity is a multidimensional behaviour (see Section 1.4), the ideal instrument for measuring it does not exist as it is not possible for a single instrument to adequately measure all the dimensions of physical activity [29]. The choice of instrument should be guided by the research question [30]. For example, accelerometers are useful when assessing patterns of physical activity but provide no information on the type of activities being undertaken. Self-report methods such as a questionnaires are suitable for assessing the types of activities that people do but are less able to accurately measure other dimensions of physical activity such as intensity or duration.

In order to minimise measurement error there are theoretical attributes that any instrument should have. These are:

- **Validity** - the degree to which an instrument measures what it purports to measure based on comparison with a criterion measure or gold standard [31]
- **Reliability** or consistency of measurement *i.e.*, does it give consistent results under the same measurement conditions? Reliability is a key component of validity as a measurement has to be consistent in order to be "truthful" [31]
- **Accuracy** - defined as *"the degree to which a measurement or an estimate based on measurements represents the true value of the attribute that is being measured"* [31]
- **Precision** - the quality of being sharply defined [31]. For example, a measurement of physical activity on a continuous scale is more precise than a dichotomous construct of active/ inactive.

The degree to which instruments for measuring physical activity display these attributes varies. Self-report instruments are generally less accurate and precise than movement sensors. Often the choice of instrument is a pragmatic decision informed by cost, staff time and expertise and participant burden but study design is also an issue. For example, larger studies such as surveys may sacrifice some accuracy and precision for the sake of cost by using self-report instruments whereas smaller studies, by using a more precise measure may be able to detect smaller differences between groups.

The population being studied will also inform the choice of instrument. For example, assessing habitual physical activity in children is difficult due to the nature of their physical activity patterns and because they find it more difficult than adults to accurately recall activity [32]. The acceptability to the subject of an instrument should also be considered, as this will have an impact on compliance with the study protocol. Physical activity diaries place a burden on the subjects due to the need to fill them in throughout the day whereas accelerometers are less onerous, though social acceptability of accelerometers among adolescents may be an issue [33]. Finally, the cost of the instrument, including staff training and the experience required to administer the instrument also needs to be considered.

2.2 History of physical activity measurement

The first studies of physical activity and health in epidemiology used job classification to estimate levels of physical activity and related these to disease outcome [6]. The studies of Morris *et al.* compared coronary heart disease (CHD) in London bus drivers and conductors. The sedentary drivers had higher rates of CHD than their more active conductor colleagues [9,10]. Similarly, Paffenbarger *et al.* used the job classification of San Francisco dockers as an estimate of occupational activity [34]. These studies provided the first empirical evidence that physical activity could be beneficial to health. However, studies of occupational physical activity ignored leisure-time and other types of activity- an important omission in the developed world where there are fewer physically active jobs and mechanisation has taken much of the effort out of jobs that were once physically demanding [35]. This led to the development of questionnaires (either self-report or interviewer based) and diaries specifically designed to measure habitual physical activity, including occupational and leisure activity and activities of daily living (e.g. walking or housework) [36].

Technological advances in instrumentation have allowed the development of objective methods of physical activity measurement. Objective methods of measuring physical activity have advantages over subjective methods that should enable the nature of the associations between physical activity and health to be characterised more precisely [37]. (See fuller discussion in Section 2.3.2) Accelerometers, pedometers and heart rate monitors have all been used successfully in studies of adults and children [23]. Although objective instruments, such as accelerometers, have advantages over subjective instruments they still have shortcomings and there are still issues of methodology and interpretation of data that have yet to be resolved [38]. Some of these issues may be overcome by combining objective measures. Accelerometers have been combined with heart rate monitors in a single instrument that addresses some of the disadvantages of a single instrument [39]. Such instruments require reliability and validity studies to be conducted before they can be accepted for use in the field but they represent a potential advance in understanding the relationship between physical activity and health.

2.3 Methods of physical activity measurement

2.3.1 Self-report methods

Table 2.1 summarises the advantages and disadvantages of some objective and subjective methods of measuring physical activity. Self-report instruments include diaries, questionnaires (sometimes administered by interview) and proxy reports *i.e.*, parental report of children's activity. These instruments have advantages - they are relatively cheap and easy to administer and can therefore be used in large epidemiological studies [37]. Self-report measures have been successful in demonstrating the relationships between physical activity and health, although their limitations have made it difficult to provide precise guidelines about the optimum frequency and intensity of activity that is required to maintain health [37]. These limitations include difficulties in respondents recalling the intensity (particularly low intensity activity which is less easily recalled than high intensity activity [40]) and duration of bouts of activity [36]; reactivity (in the case of diaries), the phenomenon where subjects' knowledge of being studied influences their behaviour [41]; and giving socially desirable responses [42] that is, overestimating the amount of activity done. These limitations can all impact on the reliability, validity, accuracy, and precision of the instrument [36]. Self-report instruments are not suitable for all populations. For example older people and other subgroups may have cognitive difficulties with questionnaires or diaries that affect their ability to complete them [43]. The limitations of self-report are particularly pertinent in children since the majority of children's activity is sporadic in nature and of short duration. Bailey *et al.* reported in studies of direct observation that 95% of children's physical activity bouts lasted less than 15 seconds [32]. This makes self-report methods impractical in children as recall of activities is likely to be inaccurate and interpretations of specific questions may vary [44].

2.3.2 Objective methods

A number of objective methods of assessing physical activity have been used successfully in adults and children. These include pedometers, heart rate monitors, accelerometers and direct observation. Objective methods overcome some of the limitations of subjective methods such as respondent recall and socially desirable responses though there are still issues of interpretation of data from objective instruments. Table 2.1 summarises the advantages and disadvantages of some objective and subjective methods of measuring physical activity.

2.3.2.1 Pedometers

Pedometers are the simplest method of objectively assessing physical activity. They use a horizontal lever that moves in response to vertical movement of the hip and so estimate the number of steps taken over a given period [33]. Pedometers are cheap and usually well tolerated by subjects and can therefore be used on large numbers of people [45]. However, they are limited in that they usually only count the number of steps taken over a given time period (although they can also be used to estimate distance walked) [45]. This makes them useful in studies designed to assess walking habits. They can also give estimates of overall activity given that ambulatory movements make up a large proportion of overall activity [33]. They are, however, unsuitable for describing patterns, intensity, duration or type of physical activity undertaken. Studies to test the reliability and validity of pedometers have been carried out. Treuth *et al.* in a study of 85 nine year old girls reported a 4-day intraclass correlation co-efficient (ICC) of 0.08 for one type of pedometer, indicating substantial intra-individual variability [46]. Pedometers perform better in validity studies. A systematic review reported median correlation co-efficients of 0.86 with accelerometry, 0.82 with direct observation and 0.68 with energy expenditure [47]. Like other types of motion sensors such as accelerometers, pedometers are unable to measure static exercise and perform poorly when the activity being undertaken requires large amounts of upper body movement [45] and cannot accurately assess some activities such as swimming or cycling. Despite these limitations, pedometers do have a use in physical activity research and investigations using pedometers have shown associations between step counts and measures of obesity and fatness [48]. In addition, they may be useful in encouraging increased physical activity in interventions where this is the desired outcome [49].

2.3.2.2 Heart rate monitors

Heart rate monitors use the electrical signal from the heart to measure each heartbeat. The signal is detected by a chest strap and transmitted to a receiver- usually on the wrist. The receiver has a built in clock so that the timing and patterns of changes in heart rate can be measured [50]. The use of heart rate monitoring to assess physical activity is based on the relationship between heart rate and oxygen uptake. Since physical activity results in increases in energy expenditure and oxygen uptake, measuring the heart rate provides an estimate of physical activity. Heart rate monitoring can be used to assess the frequency, intensity and duration of physical activity [50]. While the relationship between heart rate and oxygen uptake is linear over most of the intensity range, at lower levels of activity, the relationship is not linear. This may be a source of error since most people spend a large proportion of their day in sedentary and light activity. The relationship between heart rate and physical activity may also be influenced by emotional stress and type of activity undertaken [50]. Differential fitness levels among subjects mean that the heart rate for a given activity will be lower for an individual who is physically fitter [50]. This means that heart rate monitors should be calibrated for each subject by adjusting for resting heart rate [51], although regression equations to estimate energy expenditure from heart rate without individual calibration have been developed [52]. Individual calibration is time and resource consuming and may be impractical in large studies. An alternative is to use the mean of a specified number of the lowest recorded heart rates during the measurement period [50]. Despite these issues, heart rate monitoring has been successfully used to assess physical activity in studies on children [53] and adults [54]. In children, heart rate correlates well with oxygen uptake ($r = 0.80$; $p<0.001$) [55]. Similarly, in 61 adults Strath *et al.* reported a correlation of $r = 0.87$ between energy expenditure estimated by oxygen uptake and by heart rate across a range of activities after adjusting for fitness and age [56].

2.3.2.3 Accelerometers

Accelerometry-based physical activity monitors have become increasingly popular as an objective method of assessing physical activity. There are a number of commercially available monitors that work using the same principles, although some are uniaxial and detect acceleration in a single plane, some bi-directional like the Biotrainer and some are triaxial (such as the Tritrac-R3D) and are able to detect acceleration in three planes. In theory, accelerometers that detect movement in more than one plane should more accurately capture the full range of human movement. However, some studies have reported no advantage to measuring on more than one axis [57], while others have reported only small increases in the variation in activity energy expenditure assessed by doubly labelled water (R^2 for one axis 0.77 vs. 0.83 for three axes; p=0.03) [58].

The Actigraph (formerly known as the Computer Science and Applications- CSA) monitor, produced by Actigraph, LLC (Actigraph, LLC, Fort Walton Beach, Florida) is the most widely used accelerometer [59]. The Actigraph is a uniaxial accelerometer that uses a piezoelectric lever to detect acceleration ranging from 0.05 to 2.13G. As the subject moves, the lever bends and a signal is generated in proportion to the amount of acceleration, thus intensity of movement is recorded. The signal is sampled 10 times per second and the values summed over a user-specified 'epoch' [60]. One-minute epochs are generally used in field studies and this allows approximately 22 days of recording with the 7164 model (there is also another model, the 256 that has a larger memory). The ideal epoch length has been subject to discussion – it may be that shorter epoch lengths, e.g., 30 seconds, can better capture the shorter bouts of higher intensity activity that children tend to do [61]. Both models have now been superseded by the Actigraph GTM1, which has a solid-state accelerometer rather than a lever to detect acceleration (http://www.theactigraph.com/productsGT1M.asp). The internal clock in the Actigraph allows time and duration as well as intensity of activity to be monitored, thus daily patterns of physical activity can be described.

Actigraphs have been used in studies on both adults and children, including large, epidemiological field studies- the European Youth Heart Study [62] and more recently in the NHANES study in the US [63]. The Actigraph has been validated in both children and adolescents. Ekelund *et al.* assessed the Actigraph in free-living children within the European Youth Heart Study using energy expenditure measured by doubly labelled water as the criterion measure. Accelerometer output (counts) was related to physical activity level (an index of activity level; total energy expenditure/ basal metabolic rate. $r = 0.58$, $P < 0.01$) [64]. The Actigraph has been shown to be valid and reliable in children, with a between instrument correlation of 0.87 being reported. The same study reported correlations of 0.86 and 0.87 (one on each hip- $P < 0.001$) between activity counts and energy expenditure measured by indirect calorimetry [65].

2.3.2.4 Direct observation

Direct observation, regarded as the gold standard for assessing physical activity [66], seeks to "classify free living physical activity behaviours into distinct categories that can be quantified and analysed in greater detail" [67]. This technique allows the qualification as well as the quantification of physical activity so that the context and type of physical activity can be recorded. Direct observation is a useful instrument to use with children where recall of physical activity is unreliable [36,40]. Data from direct observation are usually coded using specialist software on a PC, laptop or palmtop, either from "live" observation or from the playback from a camcorder. Direct observation has proved useful as a criterion measure for validating other instruments such as accelerometers [68] but has some limitations. It is labour-intensive, requires intensive staff training and the samples are necessarily small.

2.3.2.5 Doubly-labelled water

Doubly labelled water does not measure physical activity directly but rather estimates total energy expenditure over a period from which the physical activity energy expenditure can be calculated [69]. This method uses non-radio-labelled isotopes of oxygen and hydrogen (^{18}O and ^{2}H) administered as a standard dose of water at the start of the measurement period (usually 7-21 days). The ^{18}O is eliminated from the body in CO_2 and water and the ^{2}H is eliminated as water only. The difference between the elimination rates of each isotope is an estimate of CO_2 production over the measurement period and the total energy expended during the measurement period can then be calculated using a standard equation [64]. Physical activity energy expenditure can then be calculated by subtracting dietary induced thermogenesis and resting energy expenditure from total energy expenditure [64]. Although doubly labelled water is regarded as the gold standard for estimating energy expenditure it does not measure physical activity. It is also expensive and cannot assess patterns of energy expenditure since it will only give energy expenditure for the measurement period. It is useful as a criterion measure for comparison with other instruments that are used to estimate energy expenditure [64] or in small studies relating energy expenditure to health outcomes [70].

Table 2.1 Comparison of different methods of assessing physical activity

Measure	Advantages	Disadvantages
Questionnaires and diaries	• Quantitative and qualitative data • Inexpensive • Suitable for large studies	• Reliability and validity problems associated with recall of activity • Unsuitable for children • Possible misinterpretation of questions
Activity monitors	• Objective • Used in laboratory and field • Indicates intensity, frequency and duration • Non-invasive • Provides minute by minute recording • Although costly, suitable for large studies	• Costly in large studies • Poor assessment of certain activities e.g. cycling • Relationship with EE not yet fully elucidated • Accurate monitor placement may be problematic over longer assessment periods
Heart rate monitors	• Objective • Associated with EE • Validated in laboratory and field setting • Low participant burden for shorter recording periods • Describes intensity, frequency and duration well (adults) • Although costly, suitable for large studies	• Costly in large studies • Some participant discomfort over long periods • Only useful for aerobic activities • Affected by fitness level • Stress can cause heart rate to increase • Monitor contacts may come off
Pedometers	• Objective • Inexpensive • Non-invasive • Easy to administer • Potential to promote behaviour change • Objective measure of common activity behaviour- walking • Suitable for large studies	• Only designed to assess walking • Possibility of participant tampering

Table 2.1 Comparison of different methods of assessing physical activity, continued

Measure	Advantages	Disadvantages
Direct observation	• Objective • Quantitative and qualitative data • Physical activity categories established *a priori* • Software available for data handling	• Intensive training for researchers required • Time and labour intensive therefore suitable only for small studies • Potential for "reactivity" among participants
Indirect calorimetry and doubly-labeled water	• Objective • Precise • Assesses EE accurately	• Invasive • High cost • Can't assess patterns of activity

Adapted from Dale, Welk and Matthews (2004)[30]

2.3.3 Surrogate measures of physical activity

Cardiorespiratory fitness has historically been easier to measure more precisely than physical activity and so it has been used as a surrogate measure of physical activity. Though there is evidence for a genetic component of fitness with heritability estimates ranging from 28% to 48% [71], there is also a substantial environmental influence that is largely due to physical activity [72], making fitness tests a useful method of gauging current physical activity levels. Associations between health outcomes and submaximally estimated fitness have been reported. Blair *et al.* in a meta-analysis of 67 studies concluded that fitness was more strongly associated with all-cause mortality than self-reported physical activity but that this was likely to be due to the objective nature of fitness assessments *vs.* self-report which could have resulted in misclassification [73]. Recent advances in technology, particularly with accelerometers, have improved our ability to assess physical activity objectively, which may result in fitness being used less as a proxy measure of physical activity.

Surveys of mode of travel have allowed the examination of secular trends of walking and cycling as a proxy for trends in physical activity. For example the UK National Travel Survey, which reported that the average distance walked per person per year declined from 255 miles in 1975/1976 to 189 miles in 1999/2001 while distance cycled per year declined from 51 miles to 39 miles for the same period [74].

Media use, usually television or video watching and computer use, can also be used as crude measures of physical inactivity. Time spent watching television may displace other physical activities and negative, though small, associations between time spent watching television and physical activity have been reported in children and adolescents aged 7-18 [75].

Energy intake has also been suggested as a surrogate measure of physical activity. Durnin reported that energy expenditure among 14-15 year olds has steadily decreased from the 1930s to the 1980s, while weight remained constant [76]. This is highly suggestive of a decrease in energy expenditure and therefore physical activity throughout the same period.

2.3.4 Future measures of activity

As technology advances, new instruments to measure physical activity that overcome some of the problems with the current generation of instruments are being developed. The Actiheart combines an accelerometer and a heart rate monitor in one instrument and this may overcome some of the limitations with either method alone [39]. A branched model equation that weights the output from the accelerometer or heart rate monitor according to physical activity intensity is used to decide which measurement is predominantly used to estimate physical activity [77]. The Intelligent Device for Energy Expenditure and Activity (IDEEA, MiniSun LLC, Fresno California) uses multiple accelerometers sited on the upper body, legs and feet connected to a microcomputer that is strapped to the waist. The multiple accelerometer sites allow for the detection of posture, gait and coordinated limb movements therefore providing some information on the type of physical activity being undertaken [78].

2.5 Conclusions

- Physical activity is difficult to measure accurately and precisely
- There is no ideal instrument for measuring physical activity
- The choice of method used should be guided by the research question and the population being studied
- Advances in technology have increased the precision and accuracy of instruments for measuring physical activity

Chapter 3. Physical activity and health in adults and children

This chapter will discuss the following:

- Is physical activity declining?
- The history of physical activity research
- Physical activity and health outcomes in adults and children

3.1 Introduction

This chapter will review the evidence for the health benefits of physical activity in adults and children in order to set the scene for the main research question examined in this thesis on the early life determinants of physical activity. Knowledge of what might influence physical activity is important only if physical activity is beneficial to health. The literature on adults, adolescent and childhood physical activity will all be reviewed since the lifecourse approach to health has been suggested as a useful method of studying the aetiologies of chronic diseases that may have their origins in childhood [79].

As the literature on physical activity and health is very large, this chapter relies, where possible, on systematic reviews and meta-analyses of randomised control trials. In addition, key epidemiological studies are cited, along with more recent studies where objective methods of physical activity measurement are used (as the majority of studies have used self-report methods). MEDLINE was searched for reviews with physical activity as the exposure and coronary heart disease, obesity, diabetes, cancer and mental health as the outcomes. The Cochrane Collaboration database of systematic reviews was also searched (http://www.cochrane.org/reviews/) for systematic reviews on physical activity or exercise only, as there were few enough to search the whole database without the need to combine with an outcome.

This chapter will begin with a discussion on whether physical activity has declined in recent years. Also reviewed is evidence of the associations between physical activity and the following outcomes:

- All-cause mortality in adults
- Coronary heart disease in adults
- Coronary heart disease risk factors in adults and children
- Some adult cancers
- Bone health in adults and children
- Mental health in adults and children

These outcomes were chosen due to their public health impact. For example, a recent report from the World Cancer Research Fund and the American Institute for Cancer Research [80] has stated that in the UK, chronic disease accounts for 84% of all deaths. Of these, 75% of deaths were from cardiovascular disease and cancer (42% and 33%, respectively) [80].

The relationships between cardiorespiratory fitness and health in adults and children will also be briefly reviewed. Finally, physical activity and the secondary prevention of disease will be discussed.

3.2 Is physical activity declining?

Due to advances in technology and division of labour in society, humans are now the only mammals that can eat without having to work for their food [81]. Despite this fact of modern life, for most of our evolutionary past, we had to work for our food. As Cordain *et al.* put it:

> *"The model for human physical activity patterns was established not in gymnasia, athletic fields, or exercise physiology laboratories, but by natural selection acting over eons of evolutionary experience."*[81] *(p 328)*

Estimates of our pre-farming hunter-gatherer ancestors' daily levels of energy expenditure are almost twice that of the modern male office worker- 51 kcal per kg vs. 29 kcal per kg.[82] Our genetic make-up can hardly have changed in the last 10,000 years and we still largely carry the genetic inheritance of our evolutionary past. This mismatch between the physical demands of our past and those of modern life is thought to be partly responsible for some of the chronic, degenerative diseases that are prevalent in our society [82].

Although labour-saving devices have been developed throughout the centuries, it is mainly during the latter half of the last century with the advent of the car, the decline of physically active jobs and the increase in sedentary alternatives that physical activity may have declined in most Western populations [83]. Accurate assessments of secular trends in physical activity are difficult as surveillance is a relatively recent phenomenon. It is widely assumed that people are less active now than they once were, although the evidence is limited [84]. Examination of other societal trends that act as proxies for physical activity may provide some evidence. In the US, total physical activity appears to have declined over the past 50 years due to declines in work, transport and domestic related physical activity and an increase in time spent in sedentary behaviours despite a concurrent increase in leisure time activity [35]. In the UK, the National Travel Survey, estimated that the average distance walked per person per year declined from 255 miles in 1975/1976 to 189 miles in 1999/2001 while distance cycled per year declined from 51 miles to 39 miles for the same period [74]. Energy intake, which may act as a proxy for energy expenditure, appears to have fallen. Durnin reported that energy expenditure among 14-15 year olds steadily decreased from the 1930s to the 1980s, while weight remained constant. This is highly suggestive of a decrease in energy expenditure and therefore physical activity throughout the same period [76].

There is, however, some conflicting evidence that suggests that 9 year old Norwegian children may have recently increased activity levels, possibly as a result of public health campaigns [85].

3.3 History of physical activity and health research

Although physical activity has long been recognised as being important to well-being [6], it is only since the 1950s that epidemiological techniques have been used to study the relationships between physical activity and health (see Section 2.2). The studies of London bus conductors and drivers [9,10] and San Francisco longshoremen [34] first showed that workers who were employed in more physically active jobs were less likely to die from coronary heart disease than their more sedentary peers. Similarly, the Harvard Alumni study followed up graduates of Harvard University and found that the more active graduates were, the more they were protected from coronary heart disease in later life [86].

Since these early studies, there has been a steady accumulation of evidence that physical activity in adults is associated with lower levels of all-cause mortality [86], coronary heart disease (CHD) [87], obesity [88], type 2 diabetes [89], hypertension [90], blood lipids [90], clustered metabolic risk [90] (e.g., hyperinsulinemia, low glucose tolerance, hyperlipidemia, hypertension, and obesity [91]), some cancers [92,93], bone health [94] and mental health [95]. In children, chronic disease mortality and morbidity are uncommon. However, physical activity in children has been associated with chronic disease risk factors such as obesity [96], metabolic risk [91], bone density [97] and also with aspects of mental health [98].

3.4 Physical activity and health outcomes

3.4.1 All-cause mortality in adults

Studies examining the relationship between physical activity and all cause mortality in adults are summarised in Table 3.1. The studies listed all show a strong graded relationship between physical activity and all-cause mortality. Most of these studies used questionnaire responses to estimate physical activity energy expenditure although one study categorised activity as low, moderate or high [99]. The use of questionnaire data for the assessment of physical activity may attenuate the estimates of the association due to measurement imprecision [37] and the self-report nature may have introduced recall bias. All studies cited are longitudinal which tends to rule out reverse causality i.e., the exposure was measured before the outcome. Although this is not proof of causality, a temporal relationship where the exposure precedes the outcome is one of Hill's criteria of causation [31].

Table 3.1 Physical activity and all-cause mortality in adults

Author(s) and year	Study design, population and sample size	Physical activity and main outcome measures	Main results
Paffenbarger *et al.*, 1986 [86]	Prospective cohort study of 16936 men aged 35-74	Questionnaire assessed leisure time activity, walking, stair climbing and created a physical activity index in kcal/week	RR[a] Walking <3 miles/week 1.00 3-8 miles/week 0.85 ≥9 miles/week 0.79 p for trend 0.0009 Stair climbing <350/week 1.00 350-1049/week 0.85 ≥1050/week 0.92 p for trend 0.0646 Physical activity index (kcal/week) <500 1.00 500-999 0.78 1000-1499 0.73 1500-1999 0.63 2000-2499 0.62 2500-2999 0.52 3000-3499 0.46 ≥ 3500 0.62 p for trend <0.0001

RR= relative risk; MET =metabolic equivalent

Table 3.1 Physical activity and all-cause mortality in adults, continued

Author(s) and year	Study design, population and sample size	Physical activity and main outcome measures	Main results
Lee *et al.*, 1995 [87]	Prospective cohort study with 22-26 year follow up of 17321 men (mean age = 46 years) with no history of cardiovascular disease	Questionnaire categorised men into quintiles of energy	RR for vigorous activities (≥6 METs) Quintile 1 1.00 Quintile 2 0.94 (0.86, 1.04) Quintile 3 0.95 (0.86, 1.05) Quintile 4 0.91 (0.83, 1.01) Quintile 5 0.91 (0.82, 1.00) p for trend 0.046
Wannamethee *et al.*, 1998 [100]	Prospective cohort study with 12-18 year follow up of 4311 men aged 52-72 with no history of cardiovascular disease	Questionnaire assessed walking, cycling, sport and recreational activity	RR Inactive or occasionally active 1.00 Lightly active 0.61 (0.43, 0.86) Moderately active 0.50 (0.31, 0.79) Moderately/vigorously active 0.65 (0.45, 0.94)
Lee and Paffenbarger 2000 [101]	Prospective cohort study with 15 year follow up of 13485 men with mean age of 57.5 years and no history of cardiovascular disease	Questionnaire assessed energy expenditure from leisure time activity, walking, stair climbing and recreational activity	RR <4200 kJ/week 1.00 4200 ≤ 8400 kJ/week 0.80 (0.72, 0.88) 8400≤ 12600 kJ/week 0.74 (0.65, 0.83) 12600 ≤ 16800 kJ/week 0.80 (0.69, 0.93) ≥ 16800 kJ/week 0.73 (0.64, 0.84)

RR= relative risk; MET =metabolic equivalent

Table 3.1 Physical activity and all-cause mortality in adults, continued

Author(s) and year	Study design, population and sample size	Physical activity and main outcome measures	Main results
Andersen et *al.*, 2000 [99]	Pooled results from 3 prospective cohort studies with average follow up of 14.5 years of 13375 women and 17265 men aged 20-93	Questionnaire assessed leisure time, work, sports and cycling activity. Four levels of activity were derived from questions although in the stratified analyses, levels 3 and 4 were combined to give 3 levels.	RR for leisure time activity Women Low activity 1.00 Moderate activity 0.65 (0.60, 0.71) Low activity 1.00 High activity 0.59 (0.52, 0.67) Men Low activity 1.00 Moderate activity 0.72 (0.66, 0.78) Low activity 1.00 High activity 0.71 (0.65, 0.78)
Carlsson et al., 2006 [102]	Longitudinal study with 2-7 year follow-up of 27734 women aged 51-83	Questionnaire assessed activity (including leisure-time, household work and work)	RR >50 METs/day 1.00 45-50 METs/day 1.05 (0.77, 1.42) 40-45 METs/day 1.09 (0.81, 1.46) 35-40 METs/day 1.26 (0.94, 1.70) ≤35 METs/day 2.56 (1.85, 3.53)

RR= relative risk; MET =metabolic equivalent

3.4.2 Coronary heart disease morbidity in adults

Table 3.2 lists studies, including a systematic review, that have examined the relationship between physical activity and coronary heart disease morbidity in adults. O'Connor *et al*'s case control study shows a graded relationship between amount of physical activity and odds ratio (OR) of myocardial infarction for men only. There was no clear relationship among women [103]. Oguma and Shinoda-Taqawa's [8] systematic review of studies in women showed a dose-response relationship between physical activity and coronary heart disease morbidity (see Table 3.2). Literature between 1966 and 2003 was searched and 30 articles from 23 studies were identified. Studies were assessed for quality using a summary score from three categories: physical activity assessment method, outcome assessment method and epidemiological methods. Studies included were 18 prospective cohort studies, one retrospective and four case-control studies. A funnel plot was used to assess publication bias. The funnel plot was deemed to be symmetrical indicating little evidence of publication bias (p=0.93) [8]. Wannamethee *et al.* [100], in the British Regional Heart study of men, reported a dose-response relationship between physical activity and non-fatal myocardial infarction across four categories of physical activity.

3.4.3 Coronary heart disease risk factors in adults

Two systematic reviews are included in this section. Shaw *et al.* [104] included 43 randomised control trials in a systematic review for the Cochrane Collaboration which included 3476 overweight or obese adults (see Table 3.3). The main outcome was weight loss and the interventions compared were exercise, exercise combined with diet and a comparison of high and low intensity exercise. Secondary outcomes were systolic and diastolic blood pressure, serum triglycerides, serum high-density-lipoprotein and fasting serum glucose. Pooled results for the various outcomes were from differing numbers of trials due to differences in outcome measured between trials, therefore the sample sizes for risk factors also vary. Table 3.3 also shows the results of the review of Carroll and Dudfield [90] who systematically reviewed 15 randomised control trials with 1007 sedentary overweight and obese dislipidaemic adults. The main outcomes were the metabolic risk factors total cholesterol, low-density lipoprotein cholesterol (LDL-C), triglycerides and high-density lipoprotein cholesterol (HDL-C). Figures shown are for the pooled weighted mean difference. Only triglycerides and HDL showed any evidence of a beneficial effect of exercise and the effects were both small.

Table 3.2 Physical activity and coronary heart disease morbidity in adults

Author(s) and year	Study design, population and sample size	Physical activity and main outcome measures	Main results
O'Connor 1995 *et al.* [103]	Case-control. Cases were diagnosed as having had a myocardial infarction from hospital records. Age and sex matched controls had no history of myocardial infarction or angina. 266 men and 74 women	Questionnaire-based assessment.	OR for quartiles of PA Men Quartile 1 1.00 Quartile 2 0.60 (0.32, 1.13) Quartile 3 0.41 (0.21, 0.78) Quartile 4 0.41 (0.22, 0.77) p for trend 0.003 Women Quartile 1 1.00 Quartile 2 1.07 (0.27, 4.17) Quartile 3 2.02 (0.56, 7.38) Quartile 4 1.29 (0.31, 5.35) p for trend 0.51
Oguma and Shinoda-Tagawa 2004 [105]	Systematic review and meta-analysis. CHD morbidity was the main outcome although studies with stroke and CHD and studies with morbidity and death as the outcome were also included Women from 30 articles with a total sample size of 567463	Various questionnaires although two used fitness as the exposure.	RR for 5 levels of PA with reference as lowest PA 1.00 reference 0.83 (0.69, 0.99) 0.77 (0.64, 0.92) 0.72 (0.59, 0.87) 0.57 (0.41, 0.79) p for trend 0.014

CHD coronary heart disease; OR odds ratio; PA physical activity; RR relative risk

Table 3.2 Physical activity and coronary heart disease morbidity in adults, continued

Author(s) and year	**Study design, population and sample size**	Physical activity and main outcome measures	**Main results**
Wannamethee *et al.*, 1998 [100]	Longitudinal study with 12-18 year follow up of 4311 men aged 52-72 with no history of cardiovascular disease	Questionnaire assessed walking, cycling, sport and recreational activity. Non-fatal myocardial infarction doctor diagnosed	RR Inactive or occasionally active 1.00 Lightly active 0.80 (0.43, 1.48) Moderately active 0.62 (0.35, 1.15) Moderately/vigorously active 0.49 (0.30, 0.84)

CHD coronary heart disease; OR odds ratio; PA physical activity; RR relative risk

Table 3.3 Physical activity and coronary heart disease risk in adults

Author(s) and year	Study design, population and sample size	Main results
Shaw *et al.* (2006) [104]	Systematic review and meta-analysis of randomised control trials of exercise and/or dietary interventions with a duration of at least 3 months 3476 overweight or obese adults from 43 trials	Overweight/obesity Exercise plus diet vs. diet alone: weight loss 1.1kg (95% CI, 0.6, 1.5) greater in exercise plus diet group Exercise plus diet vs. diet alone: BMI reduction 0.4 kg/m^2 (95% CI, 0.1, 0.7) greater in exercise plus diet group High vs. low intensity exercise: weight loss 1.5kg (95% CI, 0.7, 2.3; p) in high intensity group Systolic BP Exercise vs. diet: reduction of 2 mmHg (95% CI, 0.3, 4; p=0.02) greater in diet group Exercise plus diet vs. diet alone: no difference between groups (data not shown, p=0.87) Diastolic BP Exercise vs. no treatment: mean difference 2 mmHg (95% CI, 1, 4; p=0.01) Serum cholesterol Exercise vs. no treatment: no difference between groups (data not shown, p=0.65) Serum triglycerides Exercise vs. no treatment: mean difference 0.2 mmol/L (95% CI, 0.1, 0.3; p<0.01) Serum HDL High vs. low intensity exercise with dietary change: no difference between groups (data not shown, p=0.48) Serum glucose Exercise plus diet vs. diet alone: no difference between groups (data not shown, p=0.82) Exercise vs. no treatment: mean difference 0.2 mmol/L (95% CI, 0.1, 0.3; p=0.006) High vs. low intensity exercise: mean difference 0.3 mmol/L (95% CI, 0.2, 0.5; p<0.01)

Table 3.3 Physical activity and coronary heart disease risk in adults, continued

Author(s) and year	Study design, population and sample size	Main results
Carroll and Dudfield (2004) [90]	Systematic review and meta-analysis of randomised control trials with a 12-52 week follow up. 1007 overweight or obese sedentary adults in study	Total cholesterol Exercise vs. no treatment: mean difference -0.04mmol/L (95% CI, -0.15, 0.06; p=0.29) LDL Exercise vs. no treatment: mean difference -0.005mmol/L (95% CI, -0.09, 0.08; p=0.90) Triglycerides Exercise vs. no treatment: mean difference -0.21mmol/L (95% CI,- 0.29, -0.14; p<0.001) HDL Exercise vs. no treatment: mean difference 0.046mmol/L (95% CI, 0.027, 0.065; p<0.001)

CI confidence interval; BMI body mass index; BP blood pressure; HDL high density lipoprotein; LDL low density lipoprotein

3.4.4 Coronary heart disease risk in adolescents and children

Mortality and morbidity from chronic diseases such as coronary heart disease are rare among children and adolescents so chronic disease risk factors are studied as these are detectable in the pre-clinical stages of the disease. Table 3.4 summarises the results of selected studies of the associations between physical activity and coronary heart disease risk factors in adolescents and children. The systematic review of studies that used physical activity to treat obesity in children and adolescents was inconclusive although the authors stated that the data did tend to suggest some benefit of physical activity in obesity reduction[106]. The randomised control trial of McMurray *et al.* also reported that a school-based intervention could help prevent obesity. Alhough all four arms of the trial increased the sum of skin fold measure (see Table 3.4), the exercise interventions increased by the least amounts [107]. Ness *et al.*, in 11-12 year old ALSPAC children, found that physical activity, particularly MVPA, was associated with lower levels of fatness in boys and girls with a slightly stronger association for boys [96]. Two studies, a randomised control study [107] and an analysis in ALSPAC at age 11-12 [108] both reported that physical activity had a beneficial effect on systolic and diastolic blood pressure. In contrast, Brage *et al.* reported that few risk factors for metabolic health and coronary heart disease in children were associated with physical activity (see Table 3.4).

Table 3.4 Physical activity and coronary heart disease risk in adolescents and children

Author(s) and year	Study design, population and sample size	Physical activity and main outcome measures	Main results
Summerbell et al (2003) [106]	Systematic review 245 children and adolescents aged less than 18 years from 5 randomised control trials	Various interventions to increase physical activity although no assessments of activity were reported. Obesity estimated using BMI	Physical activity to treat obesity. The authors concluded that the studies reviewed were too small to draw conclusions from. They did note that there was some data that suggested that a reduction in sedentary behaviour was beneficial for weight loss
McMurray et al (2002) [107]	Randomised control trial with exercise only, exercise plus education, education only and a control group. Intervention lasted 8 weeks. 1140 children aged 11-14	Skin fold thickness and BMI used to assess obesity. No assessment of PA although cardiorespiratory fitness was assessed before and after the intervention	Systolic BP – differences from baseline Exercise only –2.8 ±0.5 mmHg Exercise plus education –2.0 ±0.6 mmHg Education only –1.1 ±0.6 mmHg Control 1.8 ±0.6 mmHg P for difference between control vs. all other groups < 0.001 Diastolic BP – differences from baseline Exercise only –4.8 ±0.6 mmHg Exercise plus education –0.5 ±0.6 mmHg Education only 0.1 ±0.6 mmHg Control 1.4 ±0.7 mmHg P for difference between Exercise vs control and education only = 0.0001 Sum skin folds –difference from baseline Exercise only 1.4 ±0.3 mm Exercise plus education 0.9 ±0.3 mm Education only 1.9 ±0.4 mm Control 3.7 ±0.4 mm P for difference between control vs. all other groups <0.001

Table 3.4 Physical activity and coronary heart disease risk in adolescents and children, continued

Author(s) and year	Study design, population and sample size	Physical activity and main outcome measures	Main results
Ness et al (2007) [96]	Cross-sectional 5500 children aged 11-12 years	Obesity assessed by DXA[a] and defined as the fattest 10%[b]. Physical activity assessed by accelerometer and the outcome was minutes of MVPA[c].	Boys: adjusted OR[d] for obesity for an increase in daily MVPA of 15 minutes 0.30 (95% CI 0.20, 0.43; $p<0.0001$) Girls: adjusted OR for obesity for an increase in daily MVPA of 15 minutes 0.61 (95% CI 0.45, 0.83; $p<0.0001$)
Brage *et al* (2004) [109]	Cross sectional, 589 children aged about 10 years	Metabolic risk factors – blood pressure, adiposity, and serum insulin, glucose, triglycerides and HDL cholesterol were converted to Z scores and the mean taken to give a metabolic risk score. Physical activity was measured by accelerometry. Adiposity estimated using skin fold measurement.	Physical activity was inversely associated with insulin and triglycerides Z scores ($p= 0.018$ and $p= 0.052$, respectively; co-efficients not given) but not with Z scores for glucose, HDL cholesterol, blood pressure or adiposity. Physical activity was inversely associated with combined metabolic risk after adjustment for age sex, ethnicity, sexual maturation, parental smoking and socioeconomic status -0.20 (-0.035, -0.0006) $p=0.008$ This was attenuated after further adjustment for fitness -0.012 (-0.027, 0.004) $p=0.127$

[a]dual X-ray emission absorptiometry
[b]obesity adjusted for age, height, and height squared
[c]MVPA= moderate to vigorous physical activity
[d]OR= odds ratio, model adjusted for maternal education, lowest social class, birthweight, gestational age, smoking in pregnancy, obesity of mother, sleep pattern, TV viewing, and pubertal stage
[e] Adjusted for age and gender
[f]Adjusted for room temperature, time of day, child's state, mother's education and social class, mother's hypertension and child's BMI, height and pubertal status.

Table 3.4 Physical activity and coronary heart disease risk in adolescents and children, continued

Author(s) and year	Study design, population and sample size	Physical activity and main outcome measures	Main results
Leary *et al* (2007) [108]	Cross-sectional, 5505 children aged 11-12 years	Physical activity assessed by accelerometer - outcomes were counts per minute (total activity) and minutes of MVPA[c]	Systolic BP β = -0.44 (-0.59, -0.28) mmHg per 100 cpm, β = -0.66 (95% CI -0.92, -0.39) mmHg per 15 minutes/day MVPA[e] β = -0.32 (-0.53, -0.11) mmHg per 100 cpm, β = -0.53 (-0.97, -0.20) mmHg per 15 minutes/day MVPA[f] Diastolic BP β = -0.36 (-0.46, -0.25) mmHg per 100 cpm, β = -0.50 (-0.68, -0.32) mmHg per 15 minutes/day MVPA[e] β = -0.21 (-0.35, -0.06) mmHg per 100 cpm, β = -0.22 (-0.47, -0.04) mmHg per 15 minutes/day MVPA[e]

[a]dual X-ray emission absorptiometry
[b]obesity adjusted for age, height, and height squared
[c]MVPA= moderate to vigorous physical activity
[d]OR= odds ratio, model adjusted for maternal education, lowest social class, birthweight, gestational age, smoking in pregnancy, obesity of mother, sleep pattern, TV viewing, and pubertal stage
[e] Adjusted for age and gender
[f]Adjusted for room temperature, time of day, child's state, mother's education and social class, mother's hypertension and child's BMI, height and pubertal status.

3.4.5 Physical activity and cancer in adults

Several systematic reviews have provided consistent evidence that physical activity may protect against certain types of cancer. For lung cancer odds ratios of 0.87 (95% CI 0.79, 0.95) and 0.70 (95% CI 0.62, 0.79) for moderate and high leisure time physical activity, respectively were reported by Tardon *et al.* [110]. Results were similar for men and women. This meta-analysis included seven prospective cohort studies and two case-control studies. There was little evidence of publication bias from funnel plots (p=0.50) and little evidence of heterogeneity (Q=12.26; p=0.61) [110]. Physical activity has also been reported to be protective against breast cancer. A recent systematic review [111] found that there was "strong evidence" for an inverse dose-response relationship between physical activity and post-menopausal breast cancer but inconclusive evidence for a relationship between physical activity and pre-menopausal breast cancer. Due to heterogeneity between studies pooled estimates were not calculated. Rather, a "best evidence synthesis" was adopted which summarised the evidence according to methodological quality and consistency of the evidence. A risk estimate of <0.80 was defined as "decreased risk". Funnel plots suggested that publication bias was unlikely [111]. Physical activity in childhood, adolescence and young adulthood may also protect against later breast cancer. Okasha *et al.* [112] systematically reviewed the evidence associating physical activity and later breast cancer. No meta-analysis was undertaken but the authors concluded that there was some evidence to suggest that physical activity in young people offered some protection against later breast cancer [112]. The World Cancer Research Fund and the American Institute for Cancer Research have recently published a report, which concluded that:

> *"The evidence that physical activity protects against colon cancer is convincing. Physical activity probably protects against postmenopausal breast cancer, whereas the evidence suggesting that it protects against premenopausal breast cancer is limited. Physical activity probably protects against cancer of the endometrium. The evidence suggesting that physical activity protects against cancers of the lung and pancreas is limited."* [80] *P 208.*

3.4.6 Physical activity and bone health in adults and children

A systematic review by Wolff *et al.* [113] looked at the effects of exercise training on bone mass in pre- and postmenopausal women. Twenty-five articles were included. The outcomes included measures of bone mineral density (BMD) and bone mineral content (BMC) at the lumbar spine and femoral neck. Interventions were either strength or endurance training. Treatment effects were defined as the difference between the control and intervention group in the estimated percentage change per year in bone mass (a positive number favours the intervention group). Overall treatment effects for randomised control trials were 0.84 (95% CI 0.53, 1.16) for lumbar spine and 0.89 (95% CI 0.50, 1.29) for femoral neck. For non-randomised control trials, overall treatment effects were 1.85 (95% CI 1.59, 2.11) for lumbar spine and 1.39 (95% CI 0.46, 2.33) for femoral neck. Longitudinal data support the role of physical activity in protecting bone health. In the Amsterdam Growth and Health Longitudinal Study, van Mechelen *et al.* [114] reported that BMD of the lumbar spine at age 27 years (n=181) was associated with physical activity at ages 13-16 years for males (β= 0.18; $p<0.001$) and female (β= 0.56; $p<0.01$). Further analyses with physical activity classified into categories of "peak strain physical activity" also showed an association with lumbar spine BMD at age 27 years. Analyses at ages 13, 14, 15 and 16 showed associations of β= 0.18 ($p<0.05$), β= 0.17 ($p<0.05$), β= 0.09 ($p>0.05$) and β= 0.16 ($p<0.05$), respectively. All models were adjusted for gender (where genders were combined), nutritional habits, smoking, body fatness, and alcohol intake [114].

3.4.7 Physical activity and mental health in adolescents and children

Physical activity is also associated with mental health among children and young people. Ekeland *et al.* [115] conducted a systematic review that identified eight randomised control trials (214 intervention and 166 control subjects aged three to twenty years). An overall standardised mean difference (SMD) of 0.49 (95% CI 0.16, 0.81) in favour of the intervention was reported. Studies were then stratified by methodological quality to account for heterogeneity ($p=0.037$). One study with a low risk of bias had a SMD of 1.33 (95% CI 0.43, 2.23), studies with a moderate risk of bias had a SMD of 0.21 (95% CI 0.43, 2.23), while studies with a high risk of bias had a SMD of 0.57 (95% CI 0.11, 1.04). Risk of bias was assessed by compliance with five methodological criteria. Low risk studies met all criteria; moderate risk studies met three to four of the criteria while high risk studies met less than three criteria [115]. Another systematic review [116] examined the role of vigorous exercise interventions in the treatment and prevention of anxiety and depression among children and young people aged 11-19 years. Six studies showed small improvements in anxiety for the intervention group when compared with the control (SMD -0.48, 95% CI -0.97, 0.01). Five studies showed small improvements in depression for the intervention group when compared with the control (SMD -0.66, 95% CI –1.25, -0.08). The authors reported that all trials included were mostly of low quality (met two or less of seven methodological criteria) and were also heterogeneous in terms of population, intervention and instruments used (I-squared 76.1% and 80% for anxiety and depression, respectively) [116].

3.4.8 Physical activity and cardiorespiratory fitness in adults and children

Cardiorespiratory fitness has historically been easier to measure more precisely than physical activity and so it has been used as a surrogate measure (see Section 2.4.3 for a fuller discussion). Though there is evidence for a genetic component of fitness [71], there is also a substantial environmental influence that is largely due to physical activity [72]. Cardiorespiratory fitness is associated with coronary heart disease outcomes and all cause mortality [73] and can therefore be regarded as a risk factor. Fitness is also associated with "metabolic syndrome" in adults. A prospective cohort study of 10498 adults with a 5.7-year follow up, and using increasing tertiles of fitness, reported hazard ratios of 1.0 (referent), 0.74 (95% CI 0.65, 0.84), and 0.47 (95% CI 0.40, 0.54) (p for linear trend <0.001) for men. In women, hazard ratios were 1.0 (referent), 0.80 (95% CI 0.44, 1.46), and 0.37 (95% CI 0.18, 0.80) (p for linear trend =0.01), respectively [117]. In children, fitness is cross-sectionally negatively associated with fasting insulin and triglycerides, systolic blood pressure, and skin fold thickness and positively associated with HDL cholesterol, but there is little evidence of an association with fasting glucose or diastolic blood pressure [109]. A recent narrative review highlighted the equivocal nature of the relationship between cardiorespiratory fitness and coronary health in young people and concluded that there is little evidence that higher fitness in childhood is associated with coronary health in adulthood [118].

3.4.9 Physical activity and secondary prevention of disease in adults

Much of the literature discussed so far has been in relation to primary prevention of disease i.e., preventing the disease from occurring or preventing risk factors from rising above a determined level (with the exception of obesity where trials are usually conducted to reverse obesity). There is also evidence that physical activity can help treat disease or modify existing risk factors for disease. For example, a systematic review [119] of the effects of exercise interventions on type II diabetes mellitus in 377 adults from 14 studies found that glycated haemoglobin levels were decreased by 0.6% (95% CI 0.9, 0.3; $p<0.05$) in the intervention group compared to the control group. No difference in weight loss between groups was found although the intervention groups from two studies had less body fat. No difference in fasting glucose was found between intervention and control groups [119]. Karmisholt and Gotzsche [120] reviewed systematic reviews that looked at the effects of physical activity on secondary prevention of a range of health outcomes. Seventeen systematic reviews were included. Twelve trials looked at coronary heart disease and found that exercise in addition to usual care reduced all-cause mortality (OR 0.73; 95% CI 0.54, 0.98) and cardiac mortality (OR 0.69; 95% CI 0.51, 0.94). Other outcomes examined were chronic heart failure, stroke, intermittent claudication, chronic obstructive pulmonary disease (COPD), musculoskelatal disorders, depression and type II diabetes. Of these, only COPD, some musculoskelatal disorders and type II diabetes showed any benefits from exercise intervention. The authors point out that many trials were of poor quality which made it difficult to draw firm conclusions [120].

3.5 Recommendations for physical activity

The accumulated evidence of the benefits of physical activity has prompted public health bodies to publish guidelines recommending the minimum amount of physical activity that is conducive to good health. These have been published for adults and children in the UK [121] and abroad [16,17] although the empirical evidence supporting children's guidelines is less convincing [18]. UK recommendations for adults and children are [121]:

> *"For general health benefit, adults should achieve a total of at least 30 minutes a day of at least moderate intensity physical activity on 5 or more days of the week." (p 3)*

> *"Children and young people should achieve a total of at least 60 minutes of at least moderate intensity physical activity each day. At least twice a week this should include activities to improve bone health (activities that produce high physical stresses on the bones), muscle strength and flexibility." (p 3)*

3.6 Conclusions

- Evidence from the literature indicates that physical activity offers protection against some chronic diseases and their risk factors and can delay death for adults

- Physical activity may also help treat or modify existing risk factors- secondary prevention

- This evidence has provided a basis for guidelines recommending appropriate levels of physical activity for adults [16,17] [121]

- Guidelines have been issued recommending that children become more physically active, although the empirical evidence supporting children's guidelines is less extensive than that of adults [18]

Chapter 4. Review of determinants of physical activity in children

This chapter will discuss the following:

- The role of determinants in physical activity research
- Determinants of physical activity in adults
- Determinants of physical activity in children and adolescents
- Parental influences on children's physical activity
- Environmental correlates of physical activity
- Early life determinants of physical activity
- Genetic determinants of physical activity

4.1 Chapter contents

The literature on the determinants of physical activity is largely concentrated on environmental and psychosocial factors with little on early life determinants. This chapter will therefore review some of the environmental and psychosocial determinants of physical activity and one paper on the early life determinants of physical activity. Much of the literature also focuses on the correlates of physical activity i.e., cross-sectional studies, so this area will also be reviewed. Where possible, evidence from systematic reviews and meta-analyses will be cited. MEDLINE and the Cochrane database were searched for papers using the search terms "physical activity" or "exercise" and "determinants" or "correlates" or "predictors". Only hits where physical activity was the outcome and not itself a determinant were used.

4.2 The importance of identifying determinants of physical activity

Identifying the determinants or factors that influence physical activity (see Section 1.4 for definitions) is an important area of research as this can inform intervention strategies designed to increase physical activity [122]. This could allow the identification and targeting of "at risk" groups where the determinant is not modifiable e.g., gender, or the modification of determinants that are amenable to change such as parental physical activity. Although there is an extensive literature on the psychosocial and environmental factors that influence physical activity in children, much of it is cross-sectional [123], most studies have used subjective measures of physical activity [124] and little is known about the early life influences on children's physical activity [125]. Physical activity is a complex multi-factorial behaviour that is influenced by environmental and biological factors [126]. These factors can affect the type, frequency, intensity and duration of physical activity [122]. It is unlikely that any one factor will explain the large amounts of variation observed in individual levels of total physical activity or any of its dimensions. It may also be that certain factors will be more or less important for different subgroups and at different periods of development [122].

4.2.1 Determinants of physical activity in adults

Trost *et al.* systematically reviewed correlates of adult participation in physical activity [127] (See Table 4.1). The authors conducted a "semiquantitative evaluation of the results" (also known as the vote counting method [128]) in a similar manner to reviews among children and adolescents (see Section 4.2.2). This method sorts the studies into categories of no association, positive association, negative association and an indeterminate association and uses pre-specified scores based on the proportion of studies that fall into each category to judge the strength of the evidence [128]. Potential determinants were categorised into demographic and biological factors; psychological, cognitive and emotional factors; behavioural attributes and skills, social and cultural factors, physical environment and physical activity characteristics [127]. Wendel-Voos *et al.* systematically reviewed studies examining environmental determinants of physical activity in adults [129]. The authors used the

ANGELO framework, which identifies elements that discourage physical activity and promote excess energy consumption [129]. This framework distinguishes two sizes (micro and macro) and four types of environmental determinant: physical environment, socio-cultural environment, economic environment, and political environment. Studies included in the review examined determinants of total physical activity, moderate physical activity, vigorous physical activity, moderate and vigorous physical activity and walking and cycling. A variable was regarded as having "convincing evidence" of being a determinant if more than half the studies reviewed found a "statistically significant" association in the same direction. If 40-50% of studies reported an association, this was regarded as a possible determinant. A minimum of three studies was required to draw a conclusion. Few studies provided convincing evidence of a variable being associated with physical activity. Social support was associated with total physical activity, vigorous physical activity and sport and walking. Access to equipment was associated with vigorous physical activity. Having a companion was associated with moderate and vigorous physical activity and walking.

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Table 4.1 Determinants of physical activity in adults

Determinant	Trost et al	Sallis and Owen
Demographic and biological factors		
Age	– –	– –
Blue-collar occupation	–	–
Childless	+	+
Education	++	++
Gender (male)	++	++
Hereditary	++	++
High risk for heart disease	–	–
Socioeconomic status	++	++
Injury history	+	+
Marital status (married)	–	0
Overweight/ obesity	– –	00
Race/ethnicity (non-white)	– –	– –
Psychological, cognitive and emotional factors		
Attitudes	00	0
Barriers to exercise	– –	– –
Control over exercise	+	+
Enjoyment of exercise	++	++
Expects benefits	++	++
Health locus of control	0	0
Intention to exercise	++	++
Knowledge of health and exercise	00	00
Lack of time	– –	–
Mood disturbance	– –	– –
Normative beliefs	00	00
Perceived health or fitness	++	++
Personality variables	+	+
Poor body image	–	–
Psychological health	+	+
Self-efficacy	++	++
Self-motivation	++	++
Self-schemata for exercise	++	++
Stage of change	++	++
Stress	0	0
Susceptibility to illness	00	00
Value of exercise outcomes	0	0
Behavioural attitudes and skills		
Activity history during childhood	00	00
Activity history during adulthood	++	++
Alcohol	0	0
Contemporary exercise programme	0	0
Dietary habits	++	++
Past exercise	++	+
Process of change	++	++
School sports	0	00
Skills for coping with barrier	+	+
Smoking	–	00
Sports media use	0	0
Type A behaviour	+	+
Decisional balance sheet	+	+
Social and cultural factors		
Exercise models	0	0
Past family influence	0	0
Physician influence	++	++
Social isolation	–	–

Table 4.1 Determinants of physical activity in adults, continued

Determinant	Trost et al	Sallis and Owen
Social support friends/peers	++	++
Social support spouse/family	++	++
Physical environment factors		
Access to facilities: actual	+	+
Access to facilities: perceived	+	00
Adequate lighting*	0	
Climate/season	– –	– –
Cost	0	0
Enjoyable scenery*	+	
Frequently observe others exercising*	+	
Heavy traffic*	0	
Home equipment	0	+
High crime rate*	0	
Hilly terrain*	+	
Neighbourhood safety*	+	
Presence of sidewalks*	0	
Satisfaction with facilities*	+	
Unattended dogs*	0	
Urban location*	–	
Physical activity characteristics		
Intensity	–	–
Perceived effort	– –	– –

*variables only examined in updated review
++ repeated positive association with physical activity; + weak or mixed evidence of a positive association with physical activity; 00 repeated lack of association with physical activity; 0 weak or mixed lack of association with physical activity; – – repeated negative association with physical activity; – weak or mixed evidence of a negative association with physical activity

4.2.2 Correlates and determinants of physical activity in children and adolescents

Sallis *et al.* [123] systematically reviewed the correlates of physical activity in young people and conducted a "semiquantitative evaluation of the results" similar to Trost *et al.* [127] (see Section 4.3.1) Study designs included cross-sectional and prospective although the majority were cross-sectional (42 of 55 and 50 of 57 in Tables 4.2 and 4.3, respectively). Tables 4.2 and 4.3 are adapted from this review. Evidence was assessed based on the percentage of studies reporting an association. No association was defined as 0-33% of studies showing an association (summary code "0"); an inconsistent association was defined as one where 34-59% of studies showed an association (summary code "?"); a positive (or negative) association was defined as one where 60-100% of studies showed an association (summary code "+" or "–"). When four or more studies supported either an association or no association the coding was "++", "– –" or "00". Inconsistency of the evidence where the exposure had been frequently studied was indicated by a "??" coding [123]. Exposures were classed as related or not related to physical activity based on whether an association was "statistically significant". Studies were also classified according to the quality of the physical activity measure. From Table 4.2, 14 studies were classed as "self-report of poor or unknown validity"; 15 were classed as having a "self-report with acceptable reliability/validity" and 26 were classed as having an "acceptable objective measure". From Table 4.3, 36 studies were classed as "self-report of poor or unknown validity"; 15 were classed as having a "self-report with acceptable reliability/validity" and 3 were classed as having an "acceptable objective measure". Quality of physical activity measure was not related to the proportion of "significant" results [123].

At ages 4-12, the only consistent demographic or biological determinant of physical activity was gender (males had higher activity levels) and parental overweight or obesity (see Table 4.2). Physical activity intentions and preference were the only psychological factors associated with physical activity at this age. Previous involvement in physical activity and having a healthy diet were the only behavioural attributes associated with physical activity. None of the social or cultural factors were associated with physical activity and of the physical environmental factors, only access to facilities and time spent outdoors were associated with physical activity.

Table 4.2 Correlates and determinants of physical activity among 4-12 year olds

Determinant	Related to physical activity (+/–)	Proportion of studies with PA related to the exposure	Summary code
Demographic and biological factors			
Age	–	9/19	??
Ethnicity (EuroAm)	+	4/11	??
Gender (Male)	+	28/31	++
Socioeconomic status	+	4/13	00
Single parent status	+	1/4	0
BMI	–	16/31	??
Parental obesity status	+	3/5	+
Psychological, cognitive and emotional factors			
Self-esteem	0	0/6	00
Perceived competence	+	4/7	??
Self-efficacy	+	4/9	??
Body image	0	0/4	00
Attitudes, outcome expectation	+	8/14	??

Table 4.2 Correlates and determinants of physical activity among 4-12 year olds, continued

Determinant	Related to physical activity (+/–)	Proportion of studies with PA related to the exposure	Summary code
Attitude to sweat	0	0/4	00
After school activities attitudes	0	0/4	00
Dislikes PE	–	1/5	00
PA intentions	+	3/5	+
PA preference	+	3/5	+
Perceived benefits	+	1/7	00
General barriers	–	3/3	–
Behavioural attributes and skills			
Cigarette use	+	1/3	0
Alcohol intake	0	0/3	0
Healthy diet	+	3/3	+
Caloric intake	–	1/3	0
Previous PA	+	5/6	++
Social and cultural factors			
Sedentary time	–	6/15	??
Parental PA	+	11/29	??
Parental participation	+	5/10	??
Parental benefits of PA	0	1/3	0
Parental barriers to PA	0	1/3	0
Parental encouragement	+	4/13	00
Parent transports child	+	2/8	00
Parent pays PA fees	+	1/4	0
Subjective norms	+	1/3	0
Peer influence	+	1/3	0
Physical environment factors			
Access to facilities	+	3/4	+
Season (summer/spring)	+	2/4	?
Milieu (rural)	–	2/4	?
Neighbourhood safety	0	0/4	00
Time outdoors	+	3/3	+

++ = repeatedly documented positive association with physical activity; + = weak or mixed evidence of positive association with physical activity; 00 = repeatedly documented lack of association with physical activity; 0 = weak or mixed evidence of no association with physical activity; – – = repeatedly documented negative association with physical activity; – = weak or mixed evidence of negative association with physical activity; ? = indeterminate

At ages 13-18, the only consistent demographic or biological determinants of physical activity were age, ethnicity and gender (males had higher activity levels) (see Table 4.3). Achievement orientation, perceived competence and intention to be active were the only psychological factors associated with physical activity at this age. Sensation seeking, previous physical activity and community sports involvement and being sedentary at weekends and after school were the behavioural attributes associated with physical activity. Of the social and cultural factors studied, sibling physical activities, parental help with activity, parental support and support from significant others were all associated with physical activity and of the physical environmental factors, only opportunities to exercise was associated with physical activity.

Table 4.3 Correlates and determinants of physical activity among 13-18 year olds

Determinant	Related to physical activity (+/–)	Proportion of studies with PA related to the exposure	Summary code
Demographic and biological factors			
Age	–	19/27	– –
Ethnicity (EuroAm)	+	10/14	++
Gender (male)	+	27/28	++
Socioeconomic status	+	3/9	00
BMI	–	6/21	00
Psychological, cognitive and emotional factors			
Achievement orientation	+	5/6	++
Talks loudly	+	1/3	0
External locus control	–	1/4	00
Self-esteem	+	2/9	00
Perceived physical appearance	+	3/7	??
Self-efficacy	+	7/13	??
Attitudes, outcome expectation	+	3/7	??
Perceived competence	+	2/3	+
PA intentions	+	6/8	++
Self motivation	+	1/3	0
Likes PE	+	4/9	??
Benefits of PA	+	11/29	??
Stress	–	1/7	00
Depression	–	3/4	–
General barriers	–	5/15	00
Knowledge of exercise/health	+	4/7	??
Behavioural attributes and skills			
Sensation seeking	+	3/3	+
Cigarette use	–	6/15	??
Alcohol intake	+	2/13	00
Healthy diet	+	4/16	00
Meal regularity	–	2/4	0
Previous PA	+	11/12	++
Community sports	+	7/7	++
School sports	+	1/3	0
Sedentary time	–	3/12	00
Sedentary after school	–	3/3	–
Sedentary at weekend	–	3/3	–
Social and cultural factors			
Parental PA	+	9/27	00
Sibling PA	+	4/4	++
Peer modelling	0	0/5	00
Parental help	+	3/4	+
Parents support	+	2/3	+
Teacher support	0	0/6	00

Table 4.3 Correlates and determinants of physical activity among 13-18 year olds, continued

Determinant	Related to physical activity (+/–)	Proportion of studies with PA related to the exposure	Summary code
Significant other support	+	4/4	++
Peer support	+	2/5	?
Coach support	+	2/6	00
Social influence	+	6/11	??
Physical environment factors			
Equipment available	+	1/8	00
Opportunities to exercise	+	2/3	+
Sports media influence	+	1/3	0

++ = repeatedly documented positive association with physical activity; + = weak or mixed evidence of positive association with physical activity; 00 = repeatedly documented lack of association with physical activity; 0 = weak or mixed evidence of no association with physical activity; – – = repeatedly documented negative association with physical activity; – = weak or mixed evidence of negative association with physical activity; ? indeterminate.

Though few of the factors in the papers reviewed by Sallis *et al.* [123] were associated with physical activity, there could be methodological reasons why this is so. Measurement error may be one such reason. Less than half the studies used an objective measure of physical activity which may mean that associations between an exposure and physical activity were not detected due to imprecision in measurement by self-report (or parental report) [37]. The semi-quantitative or vote counting method for summarising results of studies has been criticised for being unable to distinguish between effect sizes as it relies on categorisation of results [128]. However, as the authors make clear, the diversity of variables, measures, samples and analyses across studies prevented true meta-analysis being used [123]. The authors used reported "statistical significance" to decide if a variable was related to physical activity. The use of an arbitrary threshold to decide on whether an association exists or not is problematic and may reject studies with small sample sizes or imprecise measures [130].

The review by Sallis *et al.* [123] has recently been updated by van der Horst *et al.* [131] using similar, though not identical, methods for summarising the studies. Studies were included if the publication date was between 1999 and 2005. Evidence was again assessed based on the percentage of studies reporting an association. Between 50-75% of the associations in a similar direction were considered evidence for either a positive (+) or negative (–) association or no association (0). More than 75% of the associations in the same direction were considered strong evidence for either a positive (+) or negative (–) association or no association (00). When exactly 50% of the associations were in a positive direction or if findings showed "considerable lack of consistency", the evidence was considered inconclusive [131]. Exposures were classed as related or not related to physical activity based on whether an association was "statistically significant". Table 4.4 shows a comparison of the two studies. There were some differences in results between the two studies. For example, depression was negatively associated with physical activity in the Sallis *et al.* review whereas van der Horst *et al.* found no association. However, Sallis *et al.* reviewed the evidence over almost 30 years whereas van der Horst and colleagues reviewed the evidence over 7 years. However, comparisons are difficult with this sort of semi-quantitative analysis as it relies on the number of studies showing a particular association. As more studies were available to Sallis *et al.* due to the longer time period reviewed, it is inevitable that associations are more likely to be observed. It is also unfortunate that the later review [131] used different criteria when deciding on the strength of the evidence by requiring that different proportions of studies had to show an association in the same direction before a summary code was assigned. As with the Sallis *et al.* review (see Section 4.3.1 for further detail), methodological issues may weaken the evidence presented by van der Horst *et al.* Measurement error due to imprecise assessment of physical activity, the semi-quantitative or vote counting method used, and the use of statistical significance to decide if a variable was related to physical activity all contribute to weaken the evidence summarised from the reviewed studies. However, again, as with the Sallis review, differences in variables, samples, measures and analyses in the studies reviewed make a more formal analysis difficult.

Table 4.4 Comparison of correlates of physical activity in 1970-1998 and 1998-2005

		Van der Horst et al. (1998-2005)			Sallis et al. (1970-1998)			
		No. studies with association[a]		Summary code		No. studies with association[a]		Summary code
Children		+	–			+	–	
	Male	4/4		+	Male	23/31	1/31	+
	Age	1/8	1/8	00	Age	9/19	4/19	?
	Caucasian	3/12		00	Euro-American	4/11		?
	Parental education	2/7		00	–			
	BMI/skinfolds		2/6	0	BMI	2/31	16/31	?
	Single parent	1/5		00	Single parent	1/4	2/4	0
	Self-efficacy	6/6		+	–			
	Self-perception	0/4		00	Self esteem	0/6		00
	Enjoyment of PA	2/4		0	PA preference	3/5		+
	Barriers to PA			0	General barriers		3/3	–
	TV watching	1/5		00	Sedentary time	1/15	6/15	?
	Parental PA	4/4M/1/4F		+M/00F	–			
	Parental support	4/7		+	–			
	Access to facilities	0/7		00	Access to facilities	3/4		+
	–				Parental weight	3/5		+
	–				PA intentions	3/5		+
	–				Healthy diet	3/3		+
	–				Time outdoors	3/3		+
	–				Previous PA	5/6		+
Adolescents	Male	12/12		+	Male	27/28		+
	Age	1/10	5/10	?	Age	2/27	19/27	–
Adolescents		+	–			+	–	
	Caucasian	6/13		0	Euro-American	10/14		+
	SES	3/8		0	SES	3/9	1/9	0
	Parental education	4/6		+	–			
	BMI/skinfolds		3/7	0	BMI/skinfolds	2/21	6/21	0

Table 4.4 Comparison of correlates of physical activity in 1970-1998 and 1998-2005, continued

Van der Horst et al. (1998-2005)				Sallis et al. (1970-1998)			
	No. studies with association[a]		Summary code		No. studies with association[a]		Summary code
Attitude to PA	2/3		+	Attitude to PA	3/7		?
Self-efficacy	14/17		+	Self-efficacy	7/13		?
Intention to exercise	2/4		?	Intention to exercise	6/8		+
Perceived barriers	1/14	6/14	?	General barriers		5/15	0
Perceived benefits	1/7		00	Benefits of PA	11/29		?
Sports competence	2/6		0	Perceived competence	2/3		+
Goal orientation	4/5		+	Achievement orientation	5/6		+
Self-perception	3/8		0	Body image	3/7		?
Fun/ enjoyment of PA	3/8		0	Enjoyment of PA	0/5		00
Depression		2/7	0	Depression		3/4	—
Smoking		1/3	0	Smoking		6/15	?
TV/sedentary time		1/5	0	Non-school sedentary time		3/3	—
PE	2/2		+	School sport participation	1/3		0
Parental PA	2/8		0	Parental PA	9/27		0
Family influences	10/15		+	Parental support	2/3		+
Friends support	5/7		+	Significant other support	4/4		+
Availability of facilities	2/6		+	Availability of equipment	1/8		00
—				Sensation seeking	3/3		+
—				Previous PA	11/12		+
—				Community sports	7/7		+
—				Sibling PA	4/4		+
—				Parental help	3/4		+
—				Opportunities to exercise	2/3		+

Ferreira *et al.* [132] conducted a recent systematic semiquantitative review , adopting a similar method to that of Sallis *et al.* [123] (see above). This paper was an update of the previous Sallis *et al.* review but was also broadened in scope to include neighbourhood and city level variables [132]. Much recent research has sought to examine the relationships between the physical environment i.e., the way our towns and buildings are planned and set out and levels of physical activity. Several neighbourhood variables were studied but only crime incidence (negative association) had any influence on physical activity levels. Though many studies were included in this review and many variables were studied, few met the author's criteria for providing enough evidence to indicate the existence or otherwise of an association (variable studied in at least three independent samples) [132]. As with previous reviews of this nature [123,131,133], methodological issues may weaken the evidence presented. Measurement error due to imprecise assessment of physical activity, the semi-quantitative or vote counting method used, and the use of statistical significance to decide if a variable was related to physical activity may all contribute to weaken the evidence from this review.

4.2.3 Parental influences on children's physical activity

The review by Sallis *et al.* (see Section 4.2.2) identified few parental factors that influenced physical activity in children aged 4-12 while at ages 13-18, parental support may explain some participation in physical activity [123]. A recent paper has systematically reviewed the parental correlates of physical activity among young people. Gustafson and Rhodes [133] reviewed 34 papers that met the inclusion criteria of age between 3-18; a measurement of children's physical activity and either parent's activity or children's perception of parents activity. No inclusion criteria based on study design or methodology was used. Associations between physical activity and any particular variable were deemed to be "strong" if >60% of studies reviewed showed an association, "moderate" if 34-59% showed an association and weak if <30% showed an association. No meta-analysis was carried out due to the differences between studies in the exposures and results [133].

The relationship between parental and children's physical activity was reported in 20 cross-sectional and four longitudinal studies. The authors report that the findings are mixed. In six studies parental activity was a "moderate predictor" of children's activity, while seven studies reported no association or a weak association and one study reported a negative association between parent's and children's physical activity [133]. Only one study that reported a positive association used an objective measure of physical activity (in the parents and children) while most studies used either validated or non-validated questionnaires.

Gustafson and Rhodes also reviewed studies looking at the effects of parental support on children's physical activity [133]. Sixteen cross-sectional and three longitudinal studies of which three used accelerometers and 16 used a questionnaire to assess physical activity. All of these studies but one showed a "strong positive correlation" between parental support and children's physical activity.

The role of one parent versus two parents was also reviewed. Only five studies examined this relationship. Three of these were cross-sectional and two were longitudinal and three used accelerometers while two used a self-report measure of physical activity. Four studies found that children with two active parents were more active than children with one active parent. Children with one active parent, however, tended to be more active than those with no active parents [133].

The role of parental socioeconomic status was also examined. Six studies, all using a questionnaire to assess physical activity, examined the relationship between parent's socioeconomic status and children's physical activity. Three of these studies reported a positive correlation between parental socioeconomic status and children's physical activity. This is in contrast to the systematic review of Sallis *et al.* discussed earlier, which concluded that there was little evidence of any association [123]. Two recent studies using accelerometry reported no association with parental socioeconomic status [134,135].

The review by Gustafson and Rhodes [133] employed a similar vote counting method as previously discussed reviews did [123,131] although no summary code was derived. As with previous reviews (see section 4.2.2 for further detail), methodological issues may weaken the evidence presented in this review. Measurement error due to imprecise assessment of physical activity, the semi-quantitative or vote counting method used, and the use of statistical significance to decide if a variable was related to physical activity all contribute to weaken the evidence summarised from the reviewed studies.

4.2.4 Comparison of adult and youth determinants

Gender, and to a lesser extent age (dependent on age at the time of measurement), are the two factors that are consistently associated with physical activity in both adults [127] and youth [123]. That is, males tend to be more active than females and physical activity tends to decline with age. Dietary habits, previous physical activity and exercise and access to facilities are consistently associated with physical activity in adults and children aged 4-12 [123,127]. Ethnicity, previous physical activity and exercise and support from a significant other are associated with physical activity in adults and adolescents aged 13-18 years [123,127].

4.2.5 Early life determinants of physical activity

Only one study has prospectively examined the relationship between early life factors and later physical activity in children. Hallal *et al.* looked at physical activity at age 10-12 in 4453 children from the Pelotas 1993 Birth Cohort in Brazil [125]. Physical activity was assessed by parental report at age 10-12 and included questions about school transport, and leisure time activities. Previous physical activity was also assessed in a sub-sample of 634 children at age four. At age 10-12, an inactive child was defined as "less than 300 minutes of physical activity per week" [125]. Associations between early life variables and later physical activity and physical inactivity were estimated with prevalence ratios. Variables were mutually adjusted for other variables in the model and a significance level of $p<0.20$ set for including variables as confounders. Gender, maternal education at birth, birth order and maternal reported physical activity at age four were all associated with physical inactivity at age 10-12. Table 4.5 shows the adjusted prevalence ratios for variables associated with later sedentary behaviour. Early life factors not associated with later sedentary behaviour were family income, maternal pre-pregnancy BMI; birth weight; weight gain from birth to one year, from one to four years and from four to eleven years; overweight at one and four years and maternal reported sports performance compared to other children at four years. Also reported were unadjusted associations between early life factors and estimated minutes per week of physical activity. Gender, birth weight, family income, maternal education, pre-pregnancy BMI, birth order and physical activity at age four were all associated with physical activity at age 10-12. This study provides some evidence that factors early in a child's life may influence later physical activity and physical inactivity.

Table 4.5 Determinants of physical inactivity in the Pelotas Birth Cohort

Variable	Unadjusted prevalence ratio (95% CI)	P	Adjusted prevalence ratio (95% CI)	P
Gender				
Boys	1.00		1.00	
Girls	1.30, 1.44	<0.001	1.37 (1.30, 1.44)	<0.001
Years of maternal education at birth				
0	1.00		1.00	
1-4	1.07 (0.89, 1.30)		1.08 (0.94, 1.14)	
5-8	1.05 (0.87, 1.27)		1.06 (0.88, 1.27)	
≥9	1.18 (0.98, 1.43)	0.004	1.18 (0.98, 1.42)	0.006
Birth order				
1	1.00		1.00	
2 or 3	1.03 (0.98, 1.09)		1.03 (0.98, 1.09)	
≥4	0.91 (0.84, 0.98)	0.003	0.41 (0.84, 0.98)	0.01
Physical activity at age four				
Above average	1.00		1.00	
Average	1.04 (0.87, 1.25)		0.91 (0.72, 1.15)	
Below average	1.13 (0.87, 1.25)	0.006	1.19 (0.95, 1.49)	0.03

Adapted from Hallal *et al.* [125]

Its advantages are that it is longitudinal, making the existence of a casual relationship easier to assess, and has a large sample size, giving adequate power to detect associations. This study does, however, have some limitations. First, physical activity was assessed by maternal report, which has the disadvantages inherent in all questionnaire-based methods of assessing physical activity e.g., imprecision and recall bias [36] (see Section 2.3.1 for a fuller discussion). Second, the authors do not offer many details on the questionnaire used to measure physical activity at age 10-12, including any mention of validity or reliability studies, which may weaken the evidence [136]. Third, the main outcome is sedentary behaviour (although physical activity is analysed as a secondary outcome, this model wasn't adjusted for potential confounding factors), which may be a separate entity from physical activity as a recent study found that TV viewing, a sedentary behaviour, was not associated with physical activity [137]. This makes the results of this study less easy to interpret as a physical activity study. However, unadjusted estimates of early life/ physical activity associations showed a similar pattern of associations [125]. Finally, cultural comparisons between Brazil and the UK or other countries may not be valid. For example, social patterning of physical activity may differ according to the level of development of a particular country – in less developed countries, lower socioeconomic groups may have higher levels of non-leisure time physical activity [125].

4.2.6 Genetic determinants of physical activity

Although there is substantial evidence to suggest that physical activity is influenced by environmental factors, there is also evidence that it is partly controlled by genetic factors [138]. Familial aggregation of physical activity has been observed in some studies. In the Quebec family study of 312 parents (mean age 53 years) and 384 offspring (mean age 27 years), there was 1.40-1.52 times more variation in physical activity (assessed using 3-day diaries and a questionnaire) between than within families. Heritabilities were 25%, 16%, 19% and 17% for inactivity, moderate to strenuous activity and total activity, and weekly time spent in the main activity during the previous year, respectively [139]. Further analysis of this cohort has identified specific chromosomes that may influence physical activity [140]. Other studies have reported much lower heritabilities, for example the San Antonio Family Heart Study reported a heritability of 9% for physical activity [141]. Twin studies, however, have reported levels of heritability of 49% (95% CI 40-56%) for men and women combined [142] and 57% (95% CI 49-63%) and 50% (95% CI 49-55%) for men and women, respectively [143]. The relative contributions of genes and environment to physical activity may not be stable as sports participation in youth has been reported to change with age [144].

4.2.7 The activitystat hypothesis

A recent study has proposed that physical activity in children is centrally controlled by an "activitystat" in a similar way that appetite is thought to be. This Plymouth-based study compared children from different environments and argued that the similarity in physical activity levels despite environmental differences was indicative of central control of physical activity [145]. Three groups were studied: one tested at age 5 years and again at age 6 years and consisting of 307 children; a second of 215 children aged 7-11 years from three schools with different physical education practices and socioeconomic makeup; finally a third group of 72 children aged about 6 years from Glasgow were compared with the Plymouth group at age 6 years. In all cases, physical activity levels were similar between groups, temporally, by school and by location. Alhough an interesting hypothesis, the reported lack of difference in the children's physical activity between the various environments is not conclusive. The two cities compared were described as being of "different size, culture and climate" which seems a somewhat subjective analysis. The repeat measures study of children one year apart showed that physical activity levels remained unchanged. However, this may not be surprising since the biggest observed changes in children's physical activity comes during adolescence [146]. The most convincing evidence for an activitystat comes from the data comparing physical activity in schools with different physical education policies. Physical activity during school hours was greater in the school with 9 hours per week of physical education when compared to the two schools with 1.8 and 2.2 hours of physical education but differences in total activity were small. This may suggest that children compensate for periods of environmentally driven physical activity by being less active at other times and *vice versa*. However, the schools studied were very different in nature – the school with 9 hours of timetabled PE was a "private preparatory school with some boarding facilities" [147]. Differences in the time required to spend in study could account for out of school physical activity differences. Including these factors would have made for a more robust analysis. Nevertheless, a recent study has offered some limited support for this hypothesis. Wickel *et al.*[148] compared number of steps per day in 1443 children aged 6-12 from the US, Sweden and Australia who wore a pedometer for four days. Absolute mean differences in steps between days were small (55-958) and there was no difference in variation between countries. The authors suggest that these results support the idea that physical activity may be centrally regulated. Observational data can offer some limited evidence for the central control of physical activity but experimental evidence would be required to strengthen the case for the Activitystat. Interventions to increase physical activity have met with limited success [149]. This could be seen as support for the activitystat hypothesis as the intervention group could compensate for the extra physical activity by becoming more sedentary at other times, thus attenuating differences between intervention and control groups. However, there could also be methodological reasons why many physical activity interventions fail to show increased levels of physical activity. These include failure to account for clustered data, failure to account for interaction by gender and social differences between subgroups [149]. In order to test the Activitystat hypotheses, high quality intervention studies need to be undertaken to assess whether subjects compensate for enforced activity by being sedentary the rest of the time.

4.2.8 Conclusions

- In adults, there is evidence that some factors can influence physical activity. These include demographic and biological factors; psychological, cognitive and emotional factors; behavioural attributes and skills; social and cultural factors; physical environmental factors; and physical activity characteristics.

- Few of the factors studied have much influence on children's and adolescent's physical activity, with the well-documented exceptions of gender and age. Support from others, including parents and significant others may also be a determining factor.

- There are few common factors associated with physical activity in both adults and youth.

- Although studies of early life determinants of young people's physical activity are limited, there is some evidence that factors in early life may influence physical activity in early adolescence.

- Familial aggregation of physical activity and twin studies suggest that genetics may play a part in determining physical activity.

- A recent hypothesis has suggested that physical activity may be centrally controlled in a similar fashion to appetite although there is, as yet, limited evidence to support this.

Methods section

The methods section consists of three chapters:

- Overview of Avon Longitudinal Study of Parents and Children (ALSPAC)
- ALSPAC methodology and ALSPAC data collection;
- Physical activity methodology, data collection and statistical methodology

Chapter 5. ALSPAC overview and data collection

This thesis documents the inclusion of physical activity measurement by accelerometer into a large, established cohort of contemporary children in order to examine the associations between health and physical activity and to investigate the potential early-life determinants of physical activity. In order to put this work in context, the background to ALSPAC and the data collection will be described. This chapter will therefore discuss the following:

- History of ALSPAC
- Description of ALSPAC data collection and variables that are relevant to this thesis

This chapter will present an overview of the Avon Longitudinal Study of Parents and Children (ALSPAC) and the ALSPAC data that were collected that are relevant to this thesis.

Distributions of these variables in ALSPAC are also presented here but without any formal analyses. Histograms with superimposed normal curves and number, number missing, mean, standard deviation (SD) and median and interquartile range (IQR) are shown for continuous variables while frequency tables are shown for categorical variables. All data are shown for children who were alive at one year. The methods for physical activity data collection are described in Chapter 6.

5.1 History and overview of ALSPAC

5.1.1 History of ALSPAC

The Avon Longitudinal Study of Parents and Children (www.alspac.bris.ac.uk) is a geographical birth-cohort. It was conceived at a World Health Organisation (WHO) meeting in 1985 as part of a broader Europe-wide study known as the European Longitudinal Study of Pregnancy and Childhood (ELSPAC). Note, ALSPAC was originally called the Avon Longitudinal Study of Pregnancy and Childhood but is now known as the Avon Longitudinal Study of Parents and Children. The aim of ALSPAC is:

> *"to determine how the individual's genotype combines with environmental pressures to influence health and development. The project aims to identify pathways to optimal well-being for given environments or genotypes."* [150]

ALSPAC is also known as Children of the 90s- principally to the study children and their parents and the local media and has the logo shown in Figure 5.1. The balloon logo was chosen as many hot air balloons are made at a Bristol factory and the city hosts an annual hot air balloon festival.

Figure 5.1 ALSPAC logo

5.1.2 Overview of ALSPAC

The study methodology has been described elsewhere in detail [150]. The study area comprised the former county of Avon (no longer in existence due to redrawn boundaries) and the former South West Regional Health Authority. The population of Avon was about one million and was broadly representative of the UK in terms of socio-economic status and child health outcomes such as preterm delivery, birthweight, physical or mental disability. There were, however, fewer ethnic minorities than in the UK as a whole. It was also considered a relatively stable population with little immigration or emigration. The environment comprises a mix of city urban, suburban, rural and small town urban [150].

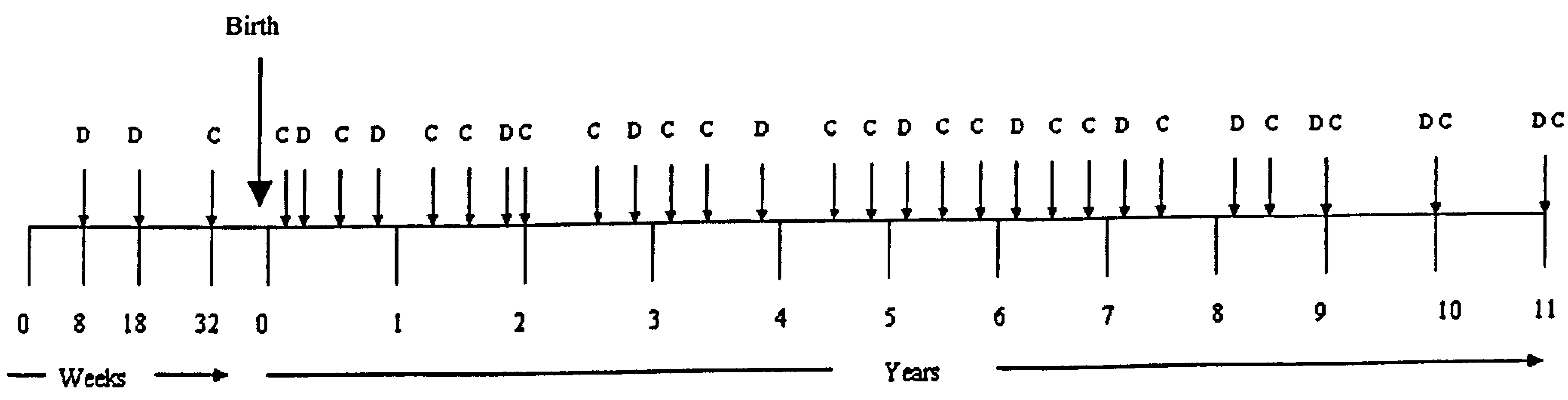
Women were eligible to enrol if they lived in Avon while pregnant and their expected delivery date was between 1st April 1991 and 31st December 1992. The mothers were recruited by advertising the study in a variety of ways such as posters in GP waiting rooms, chemists, playgroups and antenatal clinics. Additionally, eligible mothers were approached by ALSPAC staff at ultrasound scans and by midwives. There were also reports in the local and national media [150]. This resulted in 14,541 pregnant women being enrolled in the study. Of these pregnancies, 14,062 resulted in live births. The ALSPAC study team are still in contact with about 11,500 children, and of these, approximately 6000 to 8000 attend regular clinics where physical and psychological measures are carried out [151]. The clinics have been conducted since the children were aged 7 years and have taken place at ages 8, 9, 10, 11, 12, and 13, with a 15-year clinic currently ongoing.

Data are collected from the mothers, partners and children using a range of methods. These include:

- Self-report questionnaires for the mothers (about themselves and their child), the partners and, from the age of five, the children (see Figure 5.2 for details of timing of questionnaires)
- Medical and obstetric records
- Environmental exposures such as air pollutants and noise from sub-samples of homes
- A 10% sub-sample known as the Children in Focus (CiF) was followed up in more detail between the ages four months and five years- Measures such as diet, anthropometry, blood pressure, hearing and vision were recorded

Figure 5.2 shows the timing of the questionnaires sent to children and their parents from pregnancy to age 11 years. This only includes parental questionnaires and child-based questionnaires filled in by the main carer. From the age of 5.4 years, children were sent their own questionnaires. These have not been used for any analyses until the questionnaire at age 7.6 years. As this thesis examines the early life determinants of physical activity (up to age five), children's own questionnaires are not shown in Figure 5.2.

Figure 5.2 Timing of child and parent questionnaires up to year eleven of the study



C- child-based questionnaire, D- mother and partner questionnaires

5.1.3 Ethical approval in ALSPAC

Ethical approval for ALSPAC was originally obtained from the Southmead, Frenchay and Weston local Medical Research Committees and the ALSPAC Law and Ethics Committee. The ALSPAC Law and Ethics Committee includes medical ethicists, GPs, study parents, paediatricians and members of the clergy. The setting up of and work of this Committee has been described more fully elsewhere [152,153]. Ethical approval for the 11-year data collection (including the physical activity study) was obtained from the ALSPAC Law and Ethics Committee and the Local Research Ethics Committee. Ethical approval for the two sub-studies was obtained separately (see Appendix 6).

Adapted from Golding *et al.* [146]

5.1.4 Confidentiality

Confidentiality is maintained by using unique identification numbers and by separating data collection and data analysis. Each mother, partner and foetus was given a unique identification number on entry to the study. This allows longitudinal linking of data and also allows linking between mothers, partners and children. Data collected from research clinics and questionnaires are given identification numbers, which can be only linked to other data by a very limited number of computing staff. In general, researchers are not given data that might allow identification of individuals.

5.1.5 Funding of ALSPAC

ALSPAC is funded from a variety of sources. The UK Medical Research Council, the Wellcome Trust and the University of Bristol provide the core funding. Individual research projects within ALSPAC are funded by government bodies such as the UK Department of Health, and the UK Department of the Environment; charitable organisations such as the British Heart Foundation and British Lung Foundation; and individuals and commercial organizations. The US National Institutes of Health have also funded individual projects. The physical activity and obesity study that this thesis is based on was funded by the US National Heart, Lung, and Blood Institute (R01 HL071248-01A).

5.1.6 Representative nature of ALSPAC

The representative nature of ALSPAC mothers at recruitment was assessed by comparison with selected social variables from the 1991 census and with UK data from 1990. (http://www.alspac.bristol.ac.uk/protocol/rep_nature_of_sample.shtml). Table 5.1 shows these comparisons. Women in ALSPAC were more likely to own their own house, have a car, be married and be white than Avon and in the UK as a whole. They were, however, also more likely to live in accommodation with more than one person to a bedroom.

Table 5.1 Comparison of social variables between 1991 census data and ALSPAC

Variable	Area		
	ALSPAC %	Avon%	UK%
Owner occupier	79.1	68.7	63.4
1+ person/bedroom	33.5	26.0	30.8
Car in household	90.8	83.7	75.6
Married couple	79.4	71.7	71.8
Non-white mother	2.2	4.1	7.6

Table 5.2 compares height and weight variables for ALSPAC children and the rest of the UK for 1990. Heights and weights at birth, one year and two years were similar between ALSPAC and the UK as a whole.

Table 5.2 Comparison of anthropometric variables between the whole UK and ALSPAC

	ALSPAC	UK 1990	ALSPAC	UK 1990	ALSPAC	UK 1990
	Birth		One year		Two years	
			Weight (kg)			
Male	3.55	3.55	10.54	10.15	13.03	12.53
	(3.05-4.05)	(3.08-4.05)	(9.38-11.70)	(9.16-11.24)	(11.57-14.47)	(11.29-13.92)
Female	3.42	3.41	9.84	9.73	12.42	12.29
	(2.99-3.87)	(2.96-3.87)	(8.83-10.85)	(8.79-10.77)	(11.11-13.67)	(11.06-13.70)
			Length (cm)			
Male	51.3	51.1	76.5	76.2	87.5	87.8
	(49.3-53.2)	(49.1-53.1)	(74.1-80.0)	(73.7-78.8)	(84.6-90.5)	(84.6-91.0)
Female	50.4	50.2	74.6	74.4	86.2	86.5
	(48.6-52.2)	(48.3-52.1)	(72.3-76.9)	(72.0-76.8)	(83.3-89.1)	(83.4-89.6)

Figures 5.3 and 5.4 show the response rates for mother and child-based questionnaires from birth to 47 and 42 months, respectively.

Figure 5.3 Response rate for mother-based questionnaires

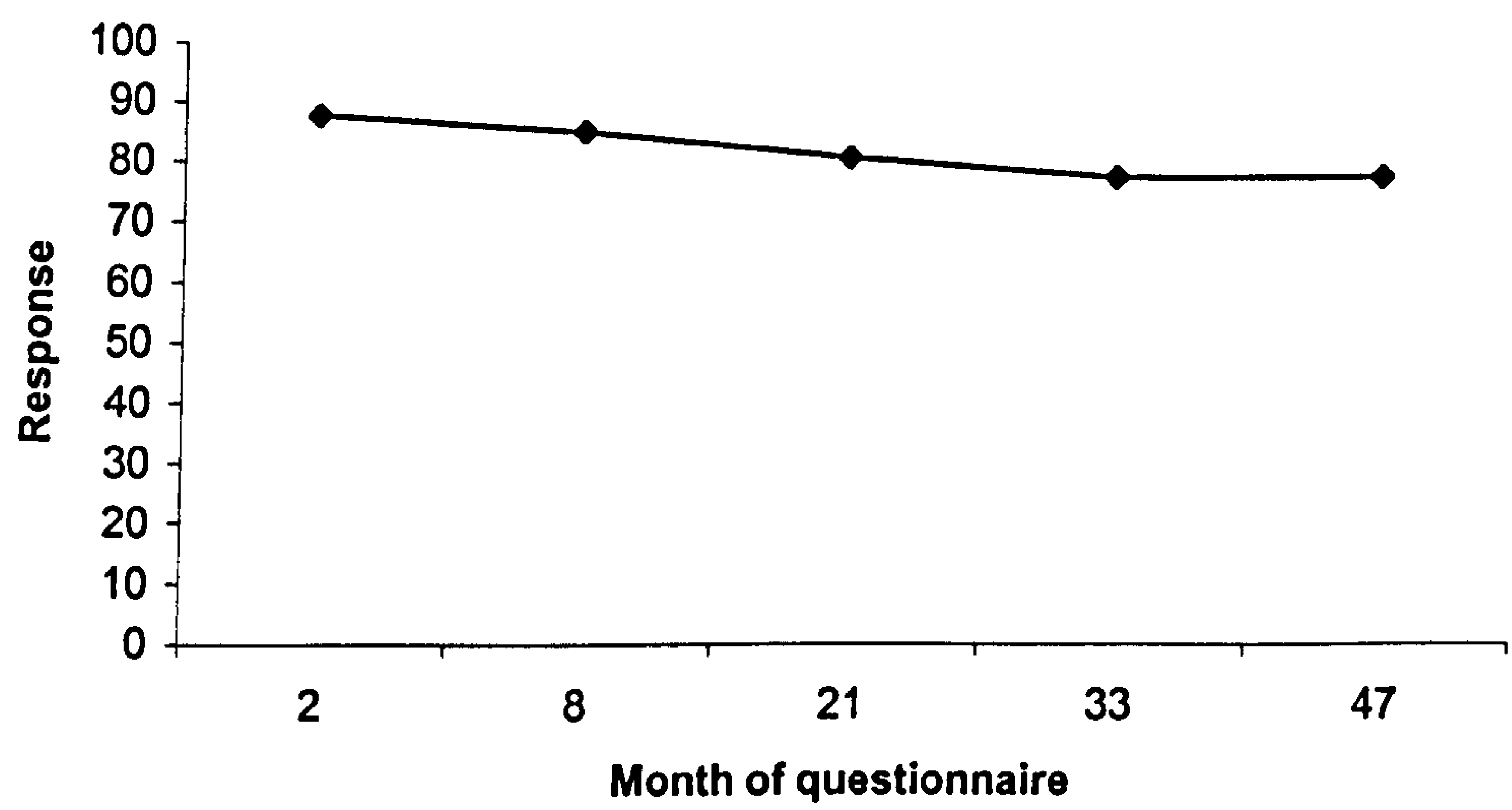
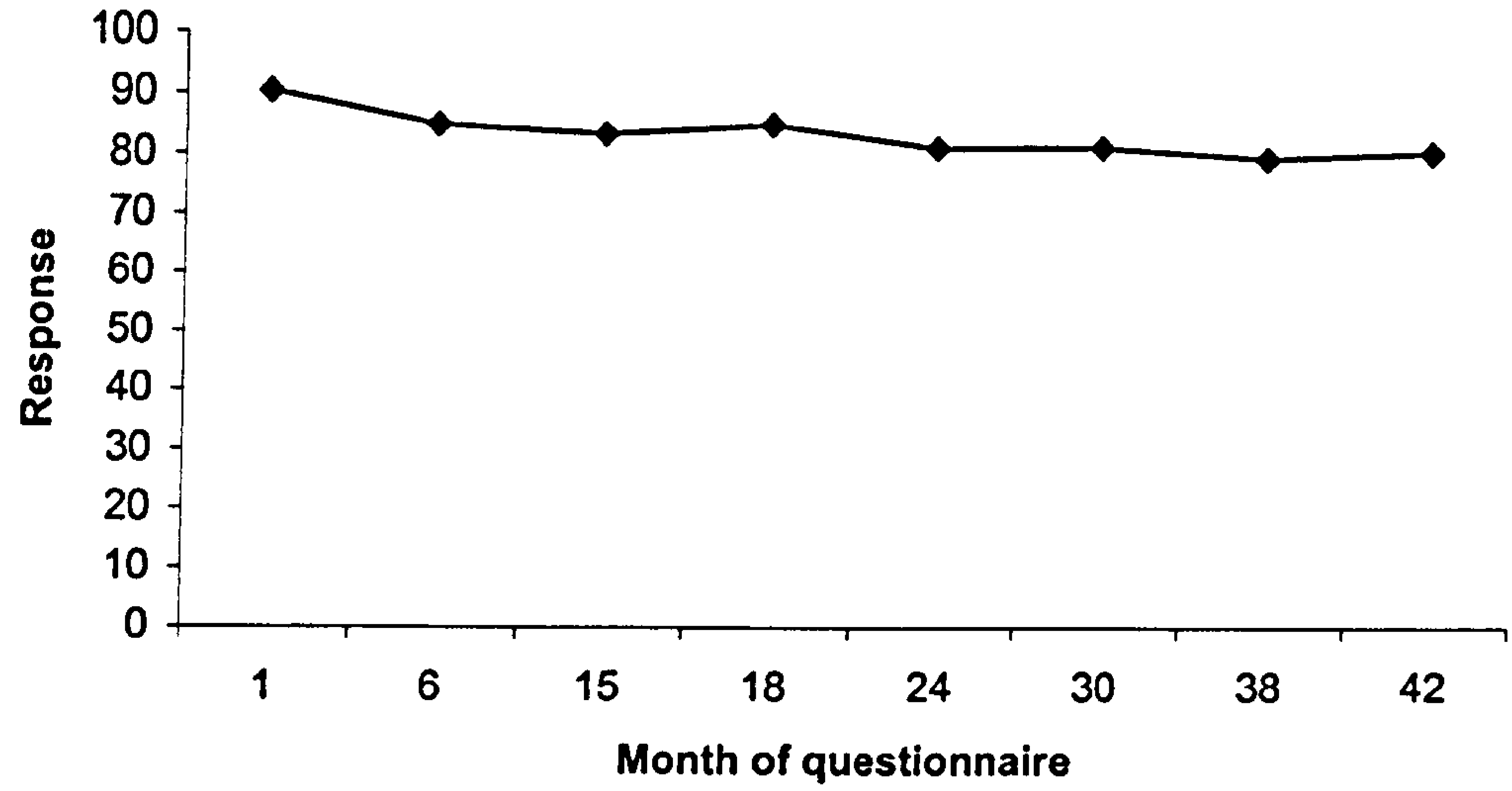


Figure 5.4 Response rate for child-based questionnaires



5.2 ALSPAC data used in this study and methods of data collection

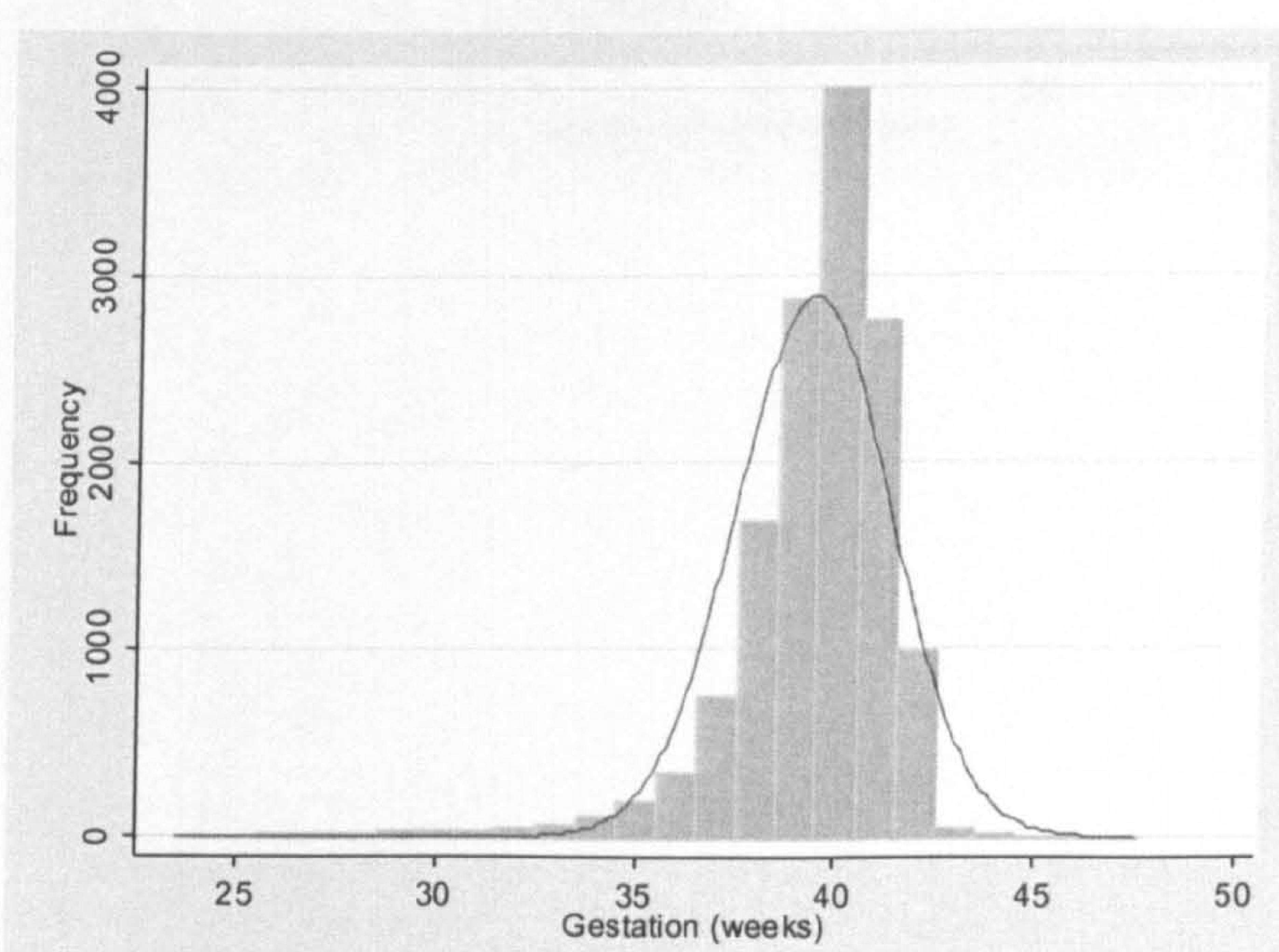
5.2.1 General points regarding data collection and coding

The data described here are "raw" data. For the analyses, some of the variables shown here will be combined to give a single variable or variable categories will be collapsed where numbers in categories are deemed too small. Multiple births are included although they were dropped from some (but not all) of the analyses due to the non-independence of such data. Children who died before one year are not included as their data will not be used in any analyses. The data used in this project are grouped into sections relating to child developmental periods. Early life was defined as pregnancy to age five years as this includes some suggested critical developmental periods in a child's life: the intrauterine period, infancy and the age of adiposity rebound. Furthermore, the age of five is a natural landmark for children as they go to school at this age and their lives therefore change markedly at around this time. The time of each data collection is the average age of the study children at data collection. For questionnaires during pregnancy, the time of the data collection was the first time the question was asked in a questionnaire. Women who were recruited in later pregnancy or at delivery were given modified questionnaires to ensure all data were collected. This means that some of the data collected for these women were collected a few months later than women who were recruited early on in pregnancy.

5.2.2 Birth outcomes

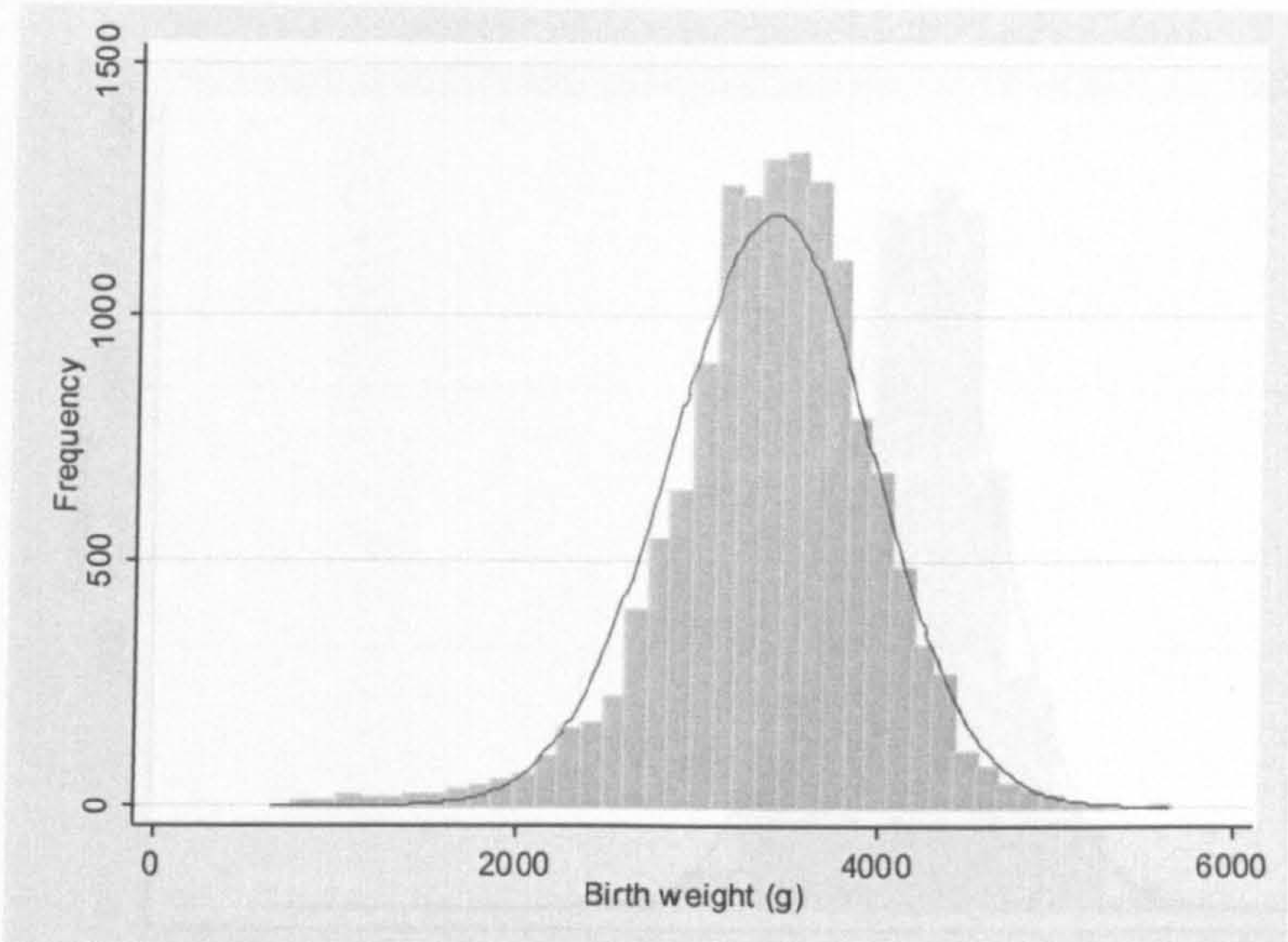
Gestational age was estimated using the date of the last menstrual period as reported by the mother at enrolment, and the date of delivery. If there was a discrepancy of more than two weeks, an estimate from the early ultrasound scan was used instead. Infant sex and birthweight were recorded at delivery and abstracted from obstetric records and/or birth notifications. Crown-heel length was measured to the nearest complete millimetre by either trained members of the ALSPAC study team using a neonatal Harpenden Neonatometer (Holtain Ltd) or extracted from clinical records. Head circumference was measured by ALSPAC staff on the same day as crown-heel length or extracted from clinical records. Ponderal index (PI) was calculated by dividing weight (in kg) by crown-heel length (in metres) cubed. Gender was extracted from birth records. Figures 5.5 to 5.9 and Table 5.3 show the distributions of these variables in all those who were alive at one year.

Figure 5.5 Gestational age (weeks)



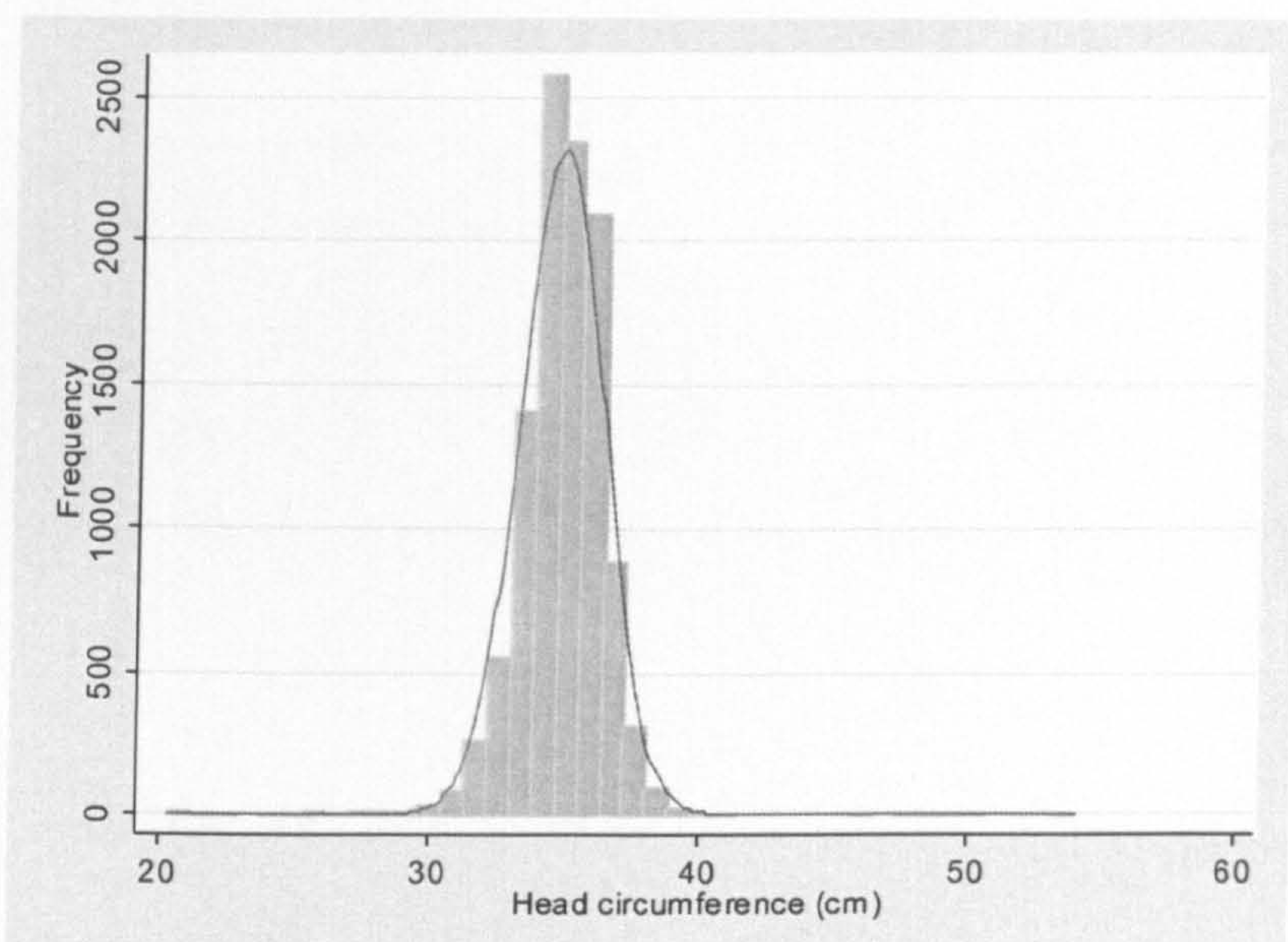
N=13978
Missing =365
Mean (SD) 39.4 (1.9)
Median (IQR) 40 (39, 41)

Figure 5.6 Birthweight (g)



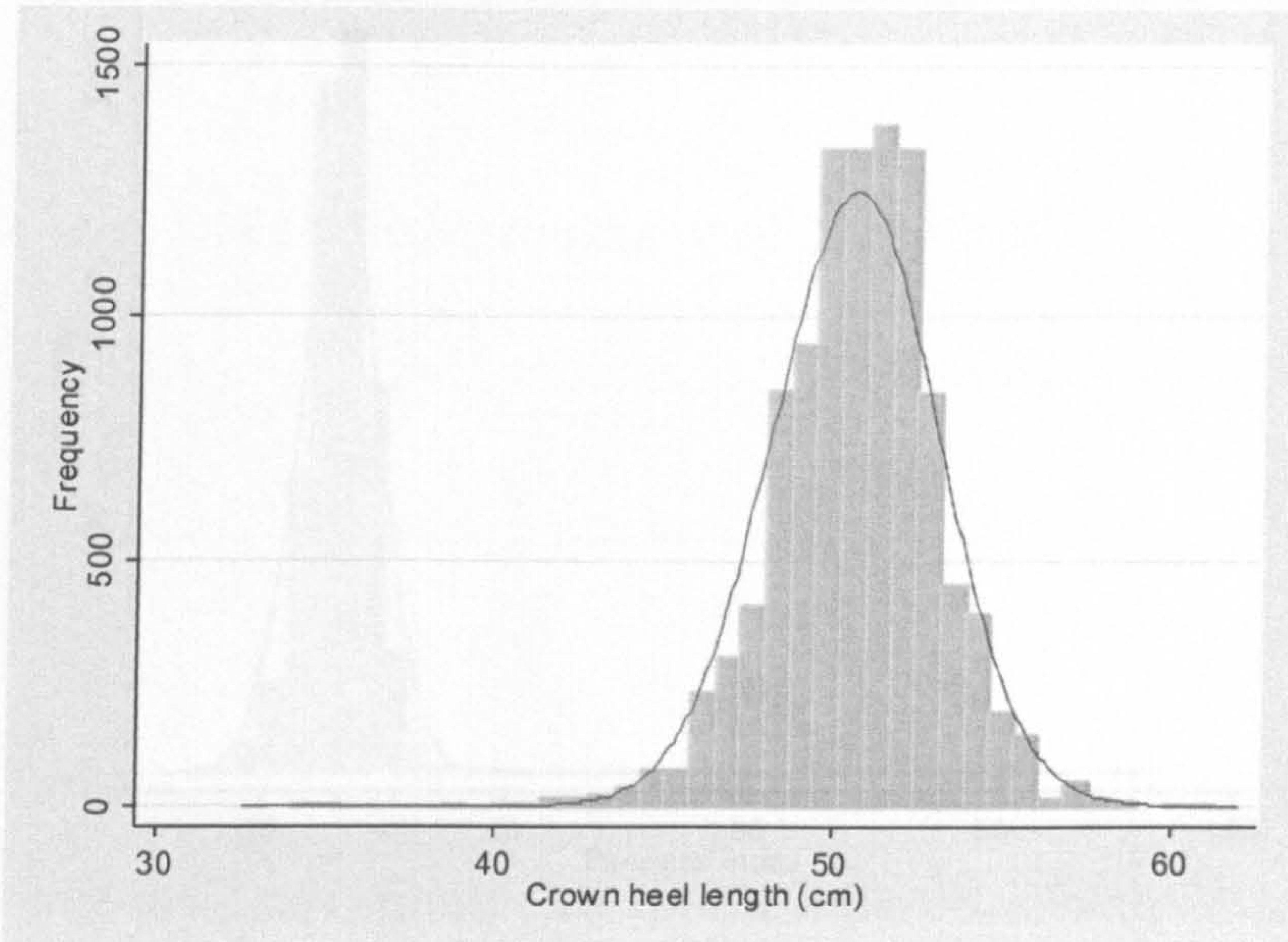
N=13798
Missing =345
Mean (SD) 3392.0 (559.2)
Median (IQR) 3420 (3090, 3740)

Figure 5.7 Head circumference (cm) at birth



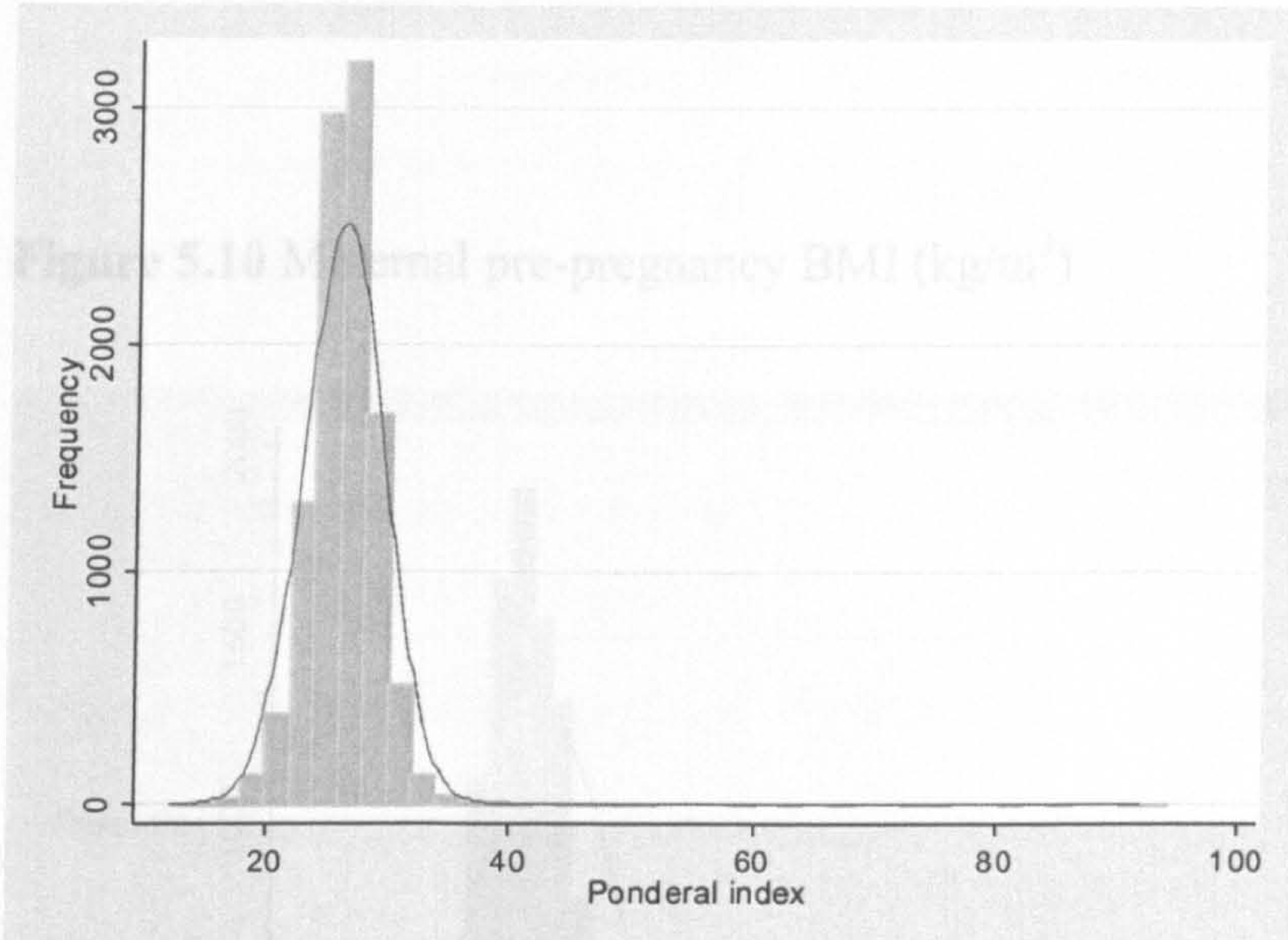
N=10693
Missing =3650
Mean (SD) 34.8 (1.6)
Median (IQR) 34.8 (33.9, 35.7)

Figure 5.8 Crown-heel length (cm)



N=10535
Missing =3808
Mean (SD) 50.6 (2.5)
Median (IQR) 50.7 (49.1, 52.0)

Figure 5.9 Ponderal index (kg/m^3) at birth



N=10418
Missing =3925
Mean (SD) 26.3 (3.3)
Median (IQR) 26.2 (24.6, 27.8)

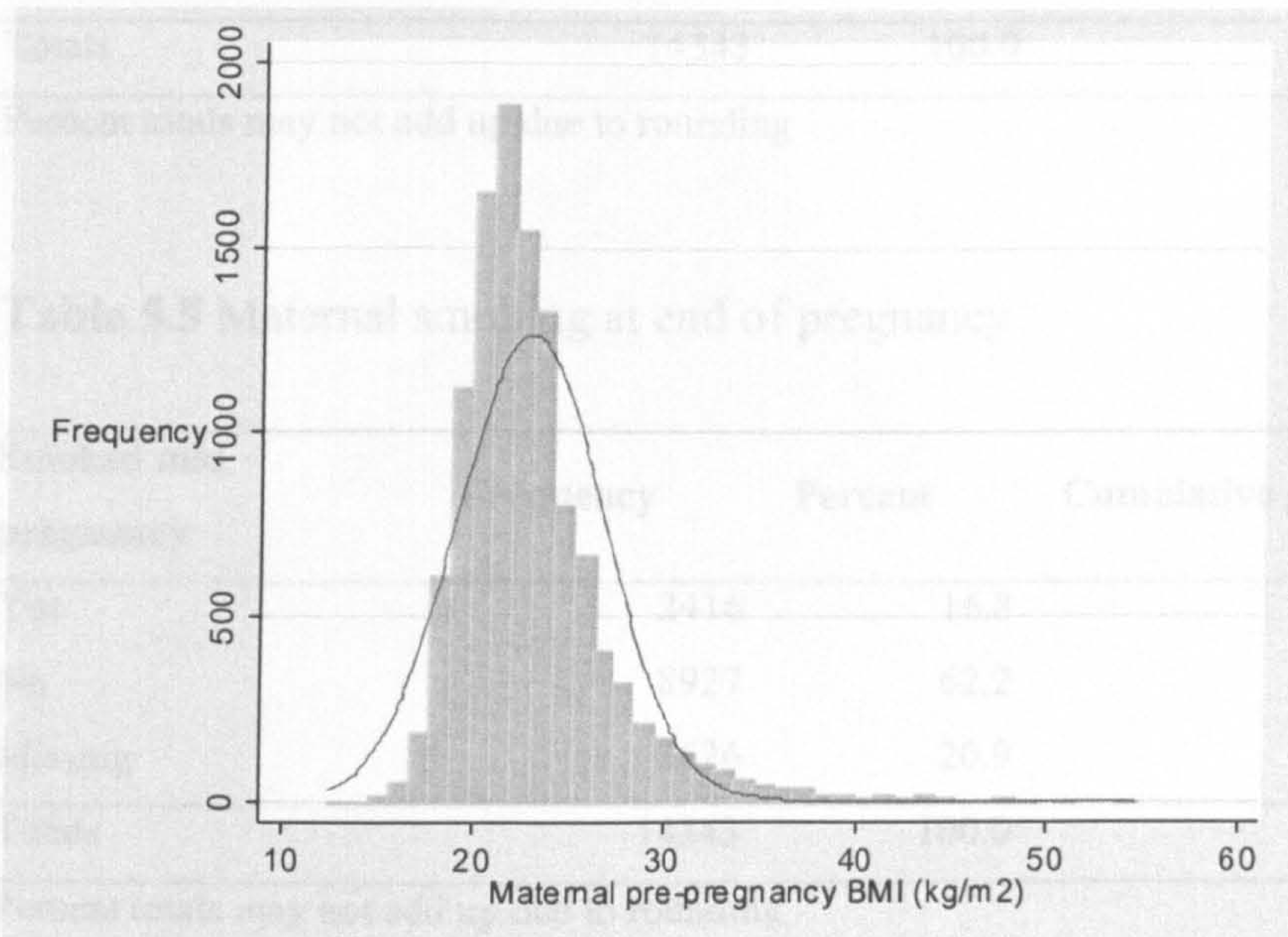
Table 5.3 Distribution of gender

Gender	Frequency	Percent	Cumulative percent
Male	7,346	51.2	51.2
Female	6,926	48.3	100.0
Missing	71	0.5	100.0
Total	14,343	100.0	

5.2.3 Prenatal exposures

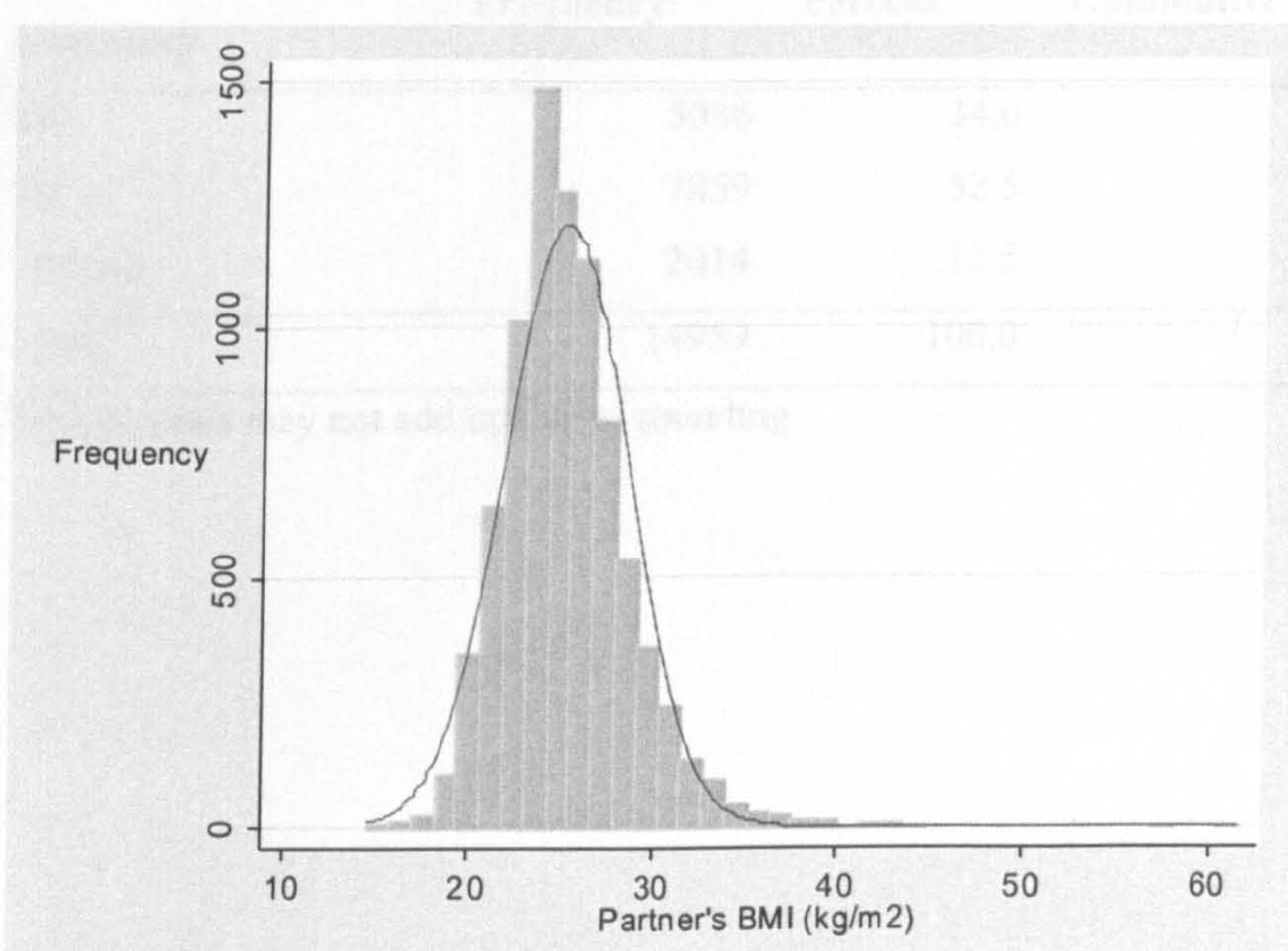
At 12 weeks gestation the mother and her partner were asked about their height and weight (pre-pregnancy weight for the mother). Body mass index (BMI) was calculated by dividing weight (kg) by height (m) squared. Data on mother's smoking during pregnancy were collected at 18 and 32 weeks gestation and were combined and coded into a binary variable, yes or no. Partners were asked about smoking during the pregnancy at 18 weeks gestation. Where data from the partner questionnaire were missing, the available data were combined with a maternal question regarding partner's smoking habits. Again this was coded as yes or no. Mother's and partner's ages at the birth of the child were calculated from their respective dates of birth and the date of birth of the child. Figures 5.10 to 5.13 and Tables 5.4 to 5.11 show the distributions of these variables in all those for whom the data were collected.

Figure 5.10 Maternal pre-pregnancy BMI (kg/m^3)



N=11535
Missing =2808
Mean (SD) 22.9 (3.8)
Median (IQR) 22.2 (20.5, 24.4)

Figure 5.11 Partner's BMI pre-pregnancy (kg/m^3)



N=8340
Missing =6003
Mean (SD) 25.2 (3.3)
Median (IQR) 24.8 (22.9, 27.0)

Table 5.4 Maternal smoking mid pregnancy

Smoked mid pregnancy	Frequency	Percent	Cumulative percent
Yes	2613	18.2	18.2
No	10545	73.5	91.7
Missing	1185	8.3	100.0
Totals	14343	100.0	

Percent totals may not add up due to rounding

Table 5.5 Maternal smoking at end of pregnancy

Smoked mid pregnancy	Frequency	Percent	Cumulative percent
Yes	2416	16.8	16.8
No	8927	62.2	79.0
Missing	3626	20.9	100.0
Totals	14343	100.0	

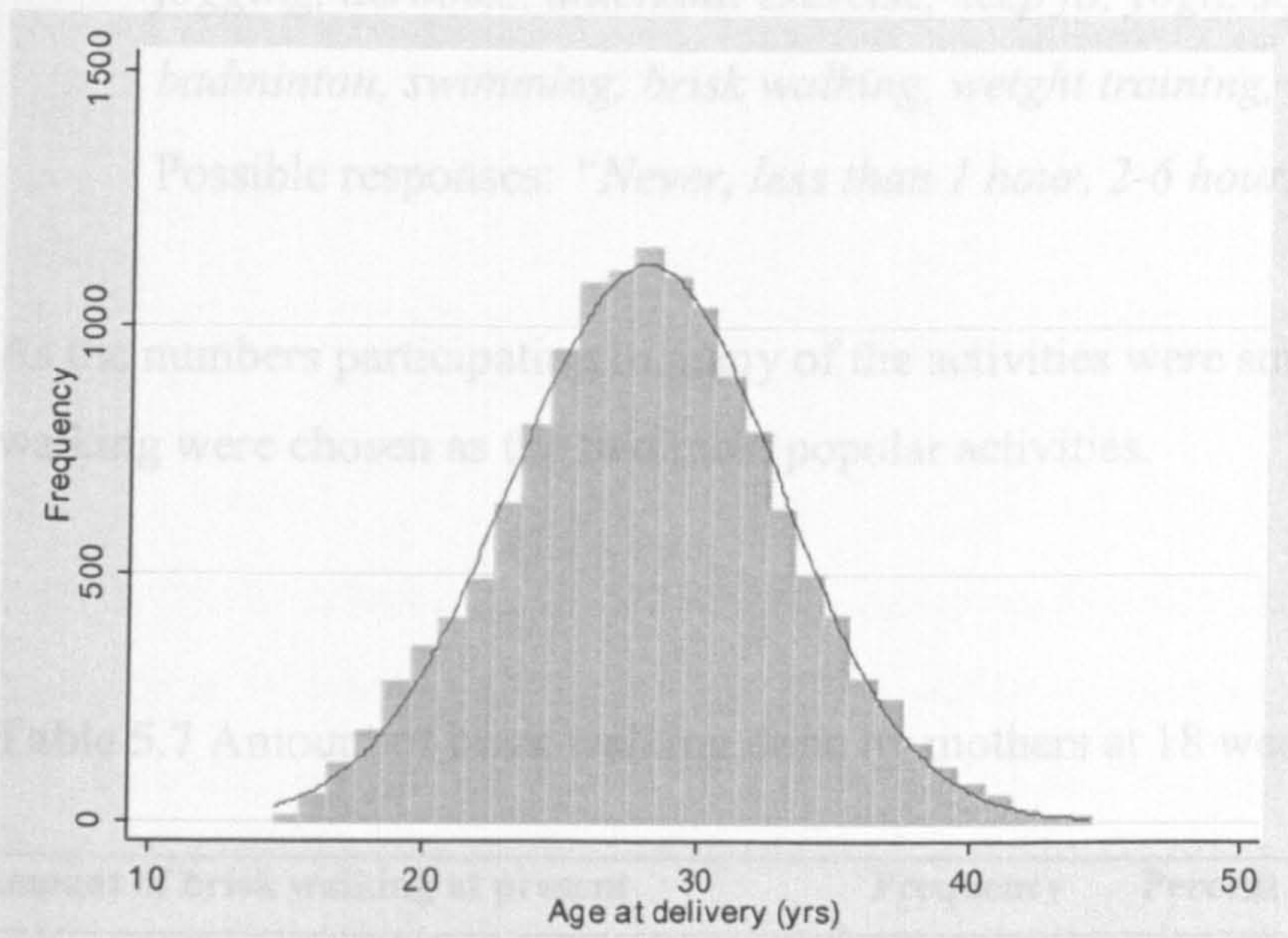
Percent totals may not add up due to rounding

Table 5.6 Partner's smoking during pregnancy

Smoked mid pregnancy	Frequency	Percent	Cumulative percent
Yes	5086	34.0	34.0
No	7859	52.5	86.5
Missing	2014	13.5	100.0
Totals	14959	100.0	

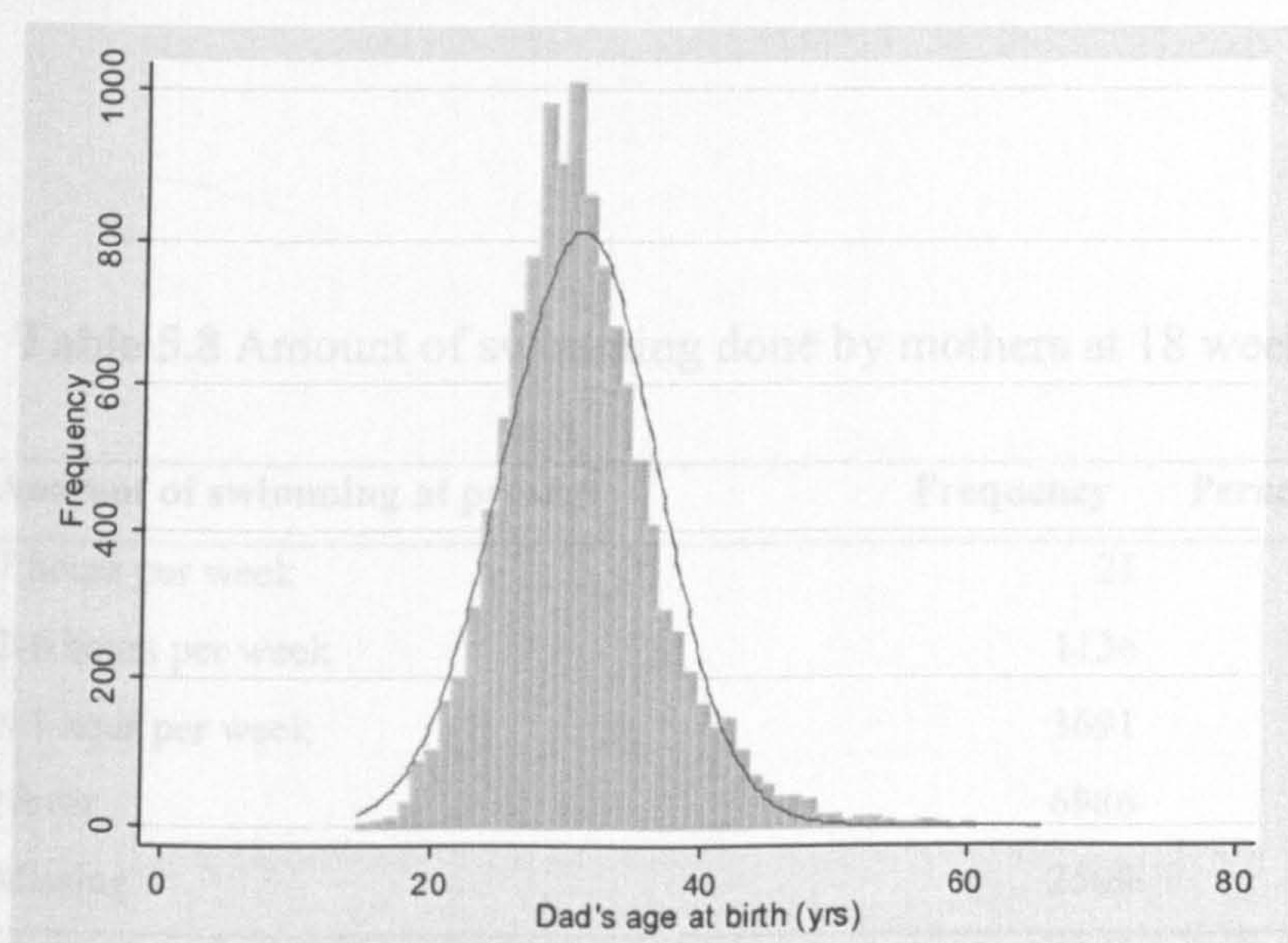
Percent totals may not add up due to rounding

Figure 5.12 Mother's age (years) at birth of child



N=13978
Missing =365
Mean (SD) 28.0 (5.0)
Median (IQR) 28 (25, 31)

Figure 5.13 Partner's age (years) at birth of child



N=11673
Missing =2670
Mean (SD) 30.7 (5.7)
Median (IQR) 30 (27, 34)

Mother's physical activity during pregnancy was assessed in the 18-week questionnaire. For this question (see below), mothers were asked how many hours per week they did from the following choices:

"How much do you do the following at present? (per week)
jogging, aerobics, antenatal exercise, keep fit, yoga, squash, tennis or badminton, swimming, brisk walking, weight training, cycling, other."
Possible responses: *"Never, less than 1 hour, 2-6 hours, more than 7 hours"*

As the numbers participating in many of the activities were small, swimming and brisk walking were chosen as the two most popular activities.

Table 5.7 Amount of brisk walking done by mothers at 18 weeks pregnancy

Amount of brisk walking at present	**Frequency**	**Percent**	**Cumulative percent**
7 hours per week	1139	7.9	7.9
2-6 hours per week	4557	31.8	39.7
< 1 hour per week	3184	22.2	61.9
Never	3069	21.4	83.3
Missing	2394	16.7	100.0
Total	14343	100.0	

Table 5.8 Amount of swimming done by mothers at 18 weeks pregnancy

Amount of swimming at present	**Frequency**	**Percent**	**Cumulative percent**
7 hours per week	21	0.2	0.2
2-6 hours per week	1136	7.9	8.1
< 1 hour per week	3691	25.7	33.8
Never	6986	48.7	82.5
Missing	2509	17.5	100.0
Total	14343	100.0	

Partner's physical activity level was derived from the 18-week questionnaire. This question asked if they were or were not doing physical activity once per week at present. This was coded as yes or no.

Table 5.9 Physical activity done by partners at 18 weeks pregnancy

Physical activity at least once per week at present	Frequency	Percent	Cumulative percent
Yes	7524	52.5	52.5
No	2324	16.2	68.7
Missing	4495	31.3	100.0
Total	14343	100.0	

Parity was the number of previous pregnancies resulting in either a live or a stillbirth, recorded at 18 weeks gestation. This was coded as a continuous variable and recoded to 0, 1, ≥2. Season of birth was calculated from birth records and was coded as: Winter= December, January, February; Spring= March, April, May; Summer= June, July, August; Autumn= September, October, November [154].

Table 5.10 Parity at 18 weeks pregnancy

Parity	Frequency	Percent	Cumulative percent
0	5728	39.9	39.9
1	4503	31.4	71.3
2	1891	13.2	84.5
3	572	4.0	88.5
4	174	1.2	89.7
5	45	0.3	90.0
6	18	0.1	90.2
7	2	0.0	90.2
8	4	0.0	90.2
11	1	0.0	90.2
13	1	0.0	90.2
22	1	0.0	90.2
Missing	1403	9.8	100.00
Total	14343	100.00	

Some percentages are 0.0 due to rounding

Table 5.11 Distribution of season of birth

Season of birth	Frequency	Percent	Cumulative percent
Spring	3167	22.1	22.1
Summer	4163	29.0	51.1
Autumn	4026	28.1	79.2
Winter	2622	18.3	97.5
Missing	365	2.5	100.0
Total	14343	100.0	

The distribution of season of birth (Table 5.11) is uneven because the recruitment period was 18 months (April 1991 to December 1992) and this meant that recruitment for January, February and March was only carried out once. This makes Spring and Winter under-represented.

5.2.4 Early childhood (0-2 years)

The mother recorded early activity in the child at 6 months postnatally using the 12 questions from a subscale of the Carey Infant Temperament Scale designed to measure Activity Level [155]. An activity score was derived from the weighted sum of these 12 questions, corrected for age and gestation. Figure 5.14 shows the distribution of this variable. Gross motor coordination was derived from 13 questions from the Denver Developmental Screening Test [156] in the 6-month postnatal questionnaire. Summing the score from the 13 questions derived a coordination score (Figure 5.15). The presence of a partner was recorded from the 8-month questionnaire and coded as yes or no (Table 5.15). Mother and partners' physical activity was recorded in the 21-month questionnaire where both were asked how many hours per week they engaged in physical activity (Tables 5.16 and 5.17).

At 32 weeks gestation the mother was asked to record her highest education level and her partner's highest education level. These were categorised into none /CSE, vocational, O level, A level or degree (Tables 5.12 and 5.13). The mother also recorded the occupation of both herself and her partner (Table 5.14), which were used to allocate them to social class groups (classes I to V with III split into non-manual and manual) using the 1991 OPCS classification [157].

Table 5.12 Mother's education

Mother's education	Frequency	Percent	Cumulative percent
None/ CSE	2505	17.5	17.5
Vocational	1224	8.5	26.0
O Level	4296	30.0	56.0
A level	2794	19.5	75.4
Degree	1600	11.2	86.6
Missing	1924	13.4	100.0
Totals	14343	100.0	

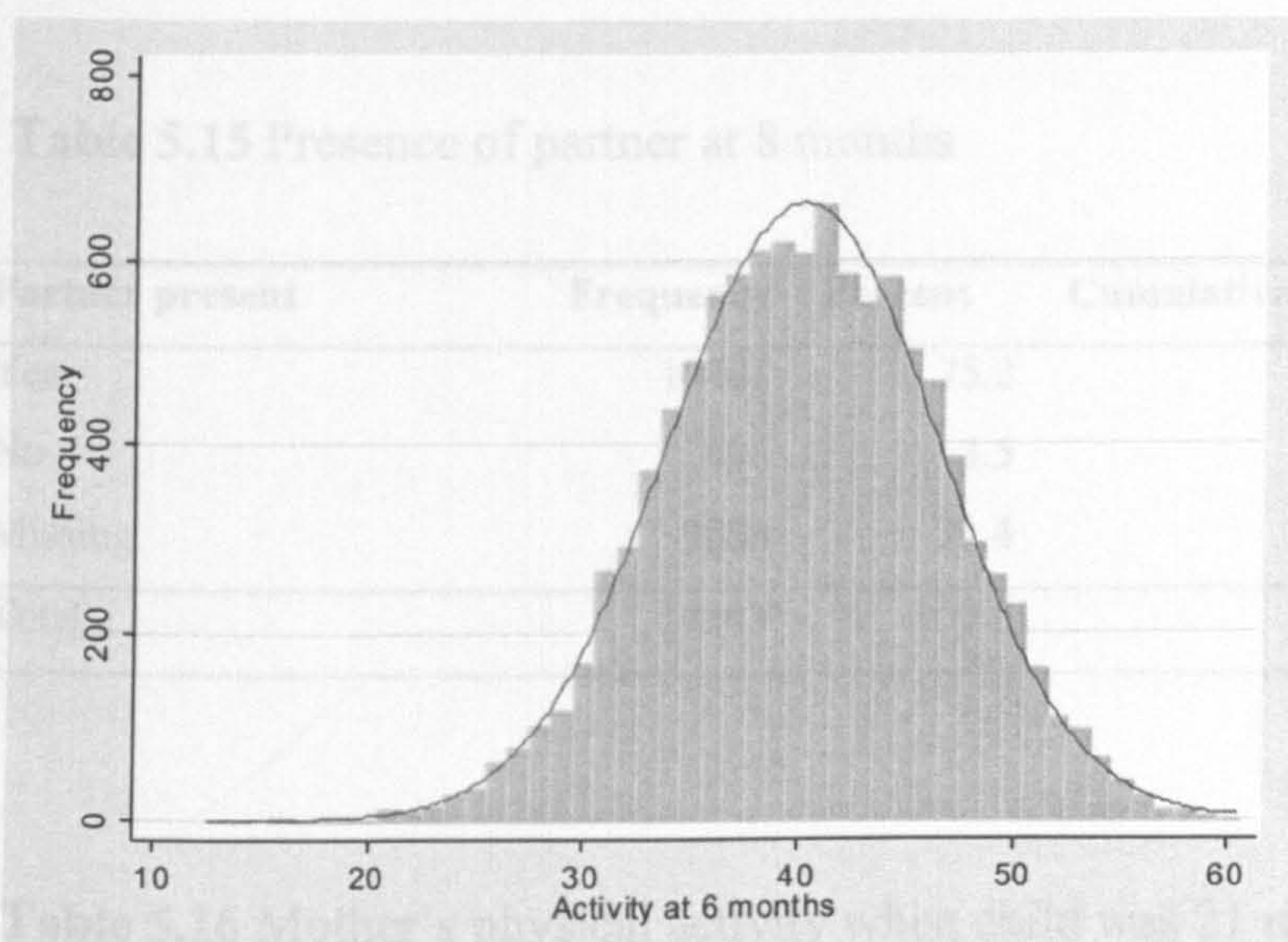
Table 5.13 Partner's education

Partner's education	Frequency	Percent	Cumulative percent
CSE	3116	21.7	21.7
Vocational	1009	7.0	28.8
O Level	2540	17.7	46.5
A level	3105	21.7	68.1
Degree	2171	15.1	83.3
Missing	2402	16.8	100.0
Totals	14343	100.0	

Table 5.14 Social class

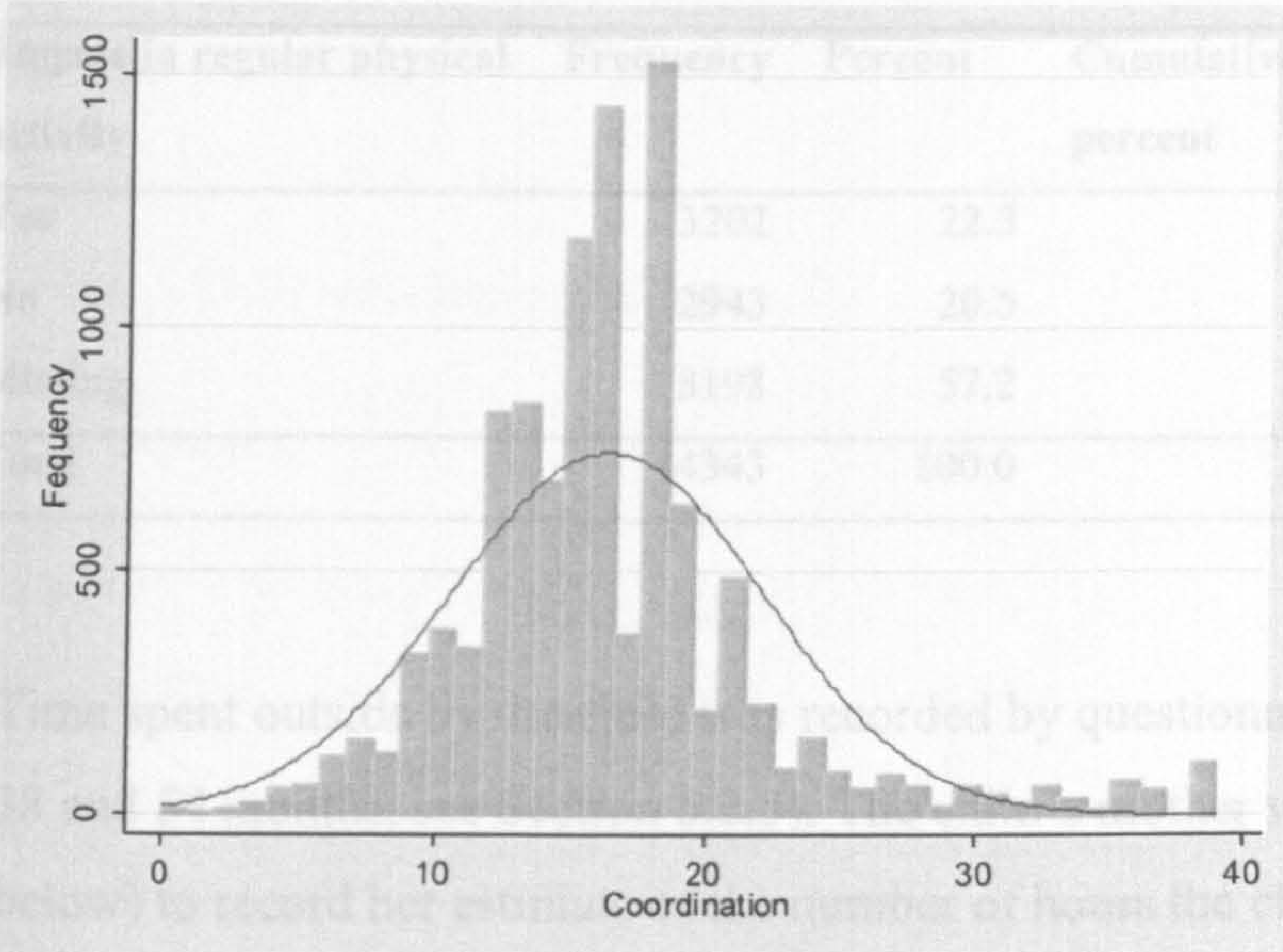
Social class	Frequency	Percent	Cumulative percent
i	374	2.6	2.6
ii	2616	18.2	20.9
iii nm	2877	20.1	40.9
m	3318	23.1	64.0
iv	1795	12.5	76.6
v	506	3.5	80.1
Missing	2857	19.9	100.0
Totals	14343	100.0	

Figure 5.14 Activity score at 6 months, adjusted for age and gestation



N=10502
Missing =4525
Mean (SD) 40.1 (6.3)
Median (IQR) 40 (36, 45)

Figure 5.15 Coordination score at 6 months



N=11077
Missing =3590
Mean (SD) 16.3 (5.8)
Median (IQR) 16 (13, 18)

Table 5.15 Presence of partner at 8 months

Partner present	Frequency	Percent	Cumulative percent
Yes	10781	75.2	75.2
No	496	3.5	78.6
Missing	3066	21.4	100.0
Total	14343	100.0	

Table 5.16 Mother's physical activity when child was 21 months

Exercise at least once per week	Frequency	Percent	Cumulative percent
Yes	4616	32.2	32.2
No	5667	39.5	71.7
Missing	4060	28.3	100.0
Total	14343	100.0	

Table 5.17 Partner's physical activity when child was 21 months

Engage in regular physical activity	Frequency	Percent	Cumulative percent
Yes	3202	22.3	22.3
No	2943	20.5	42.8
Missing	8198	57.2	100.0
Total	14343	100.0	

Time spent outside by the child was recorded by questionnaire at 24 months (and also 38 and 54 months, see Section 5.2.5). The child's mother was asked (see question below) to record her estimate of the number of hours the child spent outside in a normal week.

> *"How many hours in a normal week would you say your child spends out of doors (assuming the weather is reasonable)? Please include time spent playing, going to shops, etc.*
>
> Possible responses: *"Not at all, 1-2hrs, 3-6hrs, 7-13hrs, 14-20hrs, 21 or more"*

Table 5.18 Time outside at 24 months

Time outside	Frequency	Percent	Cumulative percent
None	8	0.1	0.1
1-2 hours	374	2.5	2.6
3-6 hours	2030	14.2	16.8
7-13 hours	2772	19.3	36.1
14-20 hours	2921	20.4	56.5
>20 hours	2215	15.4	72.0
Missing	4023	28.1	100.0
Total	14343	100.0	

Totals may not add up due to rounding

As there were small numbers in some categories, this variable was recoded as: ≤ 6, 7-13, ≥ 14 hours/week.

Breast-feeding data was collected in the 6-month questionnaire. Mothers were asked if they breast fed their child. Response choices were: Yes, still breast-feeding; Yes, stopped or Never.

Table 5.19 Breast-feeding at 6 months

Ever breast-feed	Frequency	Percent	Cumulative percent
Yes	3251	22.6	22.6
Yes, stopped	5319	37.1	59.8
Never	2756	19.2	79.0
Missing	3017	21.0	100.0
Total	14343	100.0	

Totals may not add up due to rounding

5.2.5 Pre-school (2-5 years)

At 38 months, the mother was asked to record the number of hours spent outside on week and weekend days. A total time outside score in hours per day for the whole week was derived by multiplying weekday hours by five and weekend day hours by two and summing the total. At 54 months, time outside was recorded separately for summer and winter (Tables 5.20 to 5.22). The mother was asked to record the number of hours spent outside on week and weekend days. A total time outside score in hours per day for the whole week was derived by multiplying weekday hours by five and weekend day hours by two and summing the total. For analyses (see Section 8.5.2), time spent outdoors during summer and winter at 54 months was combined into a single variable for the whole year by averaging the summer and winter variables for comparison with the 38-month outdoor data.

<u>Time outdoors at 38 months:</u>

> *"How much time on average does he/ she spend out of doors:*
> *On most weekend/weekdays**

Possible responses: *Not at all, less than 1 hour per day, 1-2 hours per day, more than 2 hours per day*

*Derived variable for whole week = (5 x weekday score) + (2 x weekend day score)."

Table 5.20 Time spent outside at 38 months

Time outside (hours/week)	Frequency	Percent	Cumulative percent
0	5	0.0	0.0
1	2	0.0	0.1
2	4	0.0	0.1
2.5	3	0.0	0.1
3.5	408	2.8	2.9
4	1	0.0	2.9
4.5	656	4.6	7.5
5	2	0.0	7.5
6	166	1.2	8.7
6.5	157	1.1	9.8
7	2532	17.7	27.4
9	2078	14.5	41.9
10	1	0.0	41.9
11	23	0.2	42.1
12	275	1.9	44.0
14	3599	25.1	69.1
Missing	4431	30.9	100.0
Total	14343	100.0	

Percent totals may not add up due to rounding. Some percentages 0.0 due to rounding

Time outdoors at 54 months:

"How much time on average does he/ she spend out of doors:
*In summer weekend/weekdays. In winter weekend/weekdays**

Possible responses: *Not at all, less than 1 hour per day, 1-2 hours per day, more than 3 hours per day*

*Derived variable for whole week = (5 x weekday score) + (2 x weekend day score)."

Table 5.21 Distribution of time outside during summer at 54 months

Time outside (hours/week)	Frequency	Percent	Cumulative percent
0	4	0.0	0.0
1	1	0.0	0.0
3.5	17	0.1	0.2
6	34	0.2	0.4
8	1	0.0	0.4
9.75	11	0.1	0.5
10.5	30	0.2	0.7
12.25	536	3.7	4.4
16.75	1638	11.4	15.8
20	2	0.0	15.9
21	3	0.0	15.9
23.5	113	0.8	16.7
28	6970	48.6	65.3
Missing	4983	34.7	100.0
Total	14343	100.0	

Percent totals may not add up due to rounding. Some percentages 0.0 due to rounding

Table 5.22 Time spent outside during winter at 54 months

Time outside (hours/week)	Frequency	Percent	Cumulative percent
0	99	0.7	0.7
1	48	0.3	1.0
2.5	47	0.3	1.4
3.5	2259	15.8	17.1
6	1680	11.7	28.8
8.75	7	0.1	28.9
9.75	455	3.2	32.0
10.5	113	0.8	32.8
12.25	3510	24.5	57.3
16.75	745	5.2	62.5
21	10	0.1	62.6
23.5	38	0.3	62.8
28	334	2.3	65.2
Missing	4998	34.9	100.0
Total	14343	100.0	

Percent totals may not add up due to rounding. Some percentages 0.0 due to rounding

Early TV viewing was recorded by questionnaire at 38 and 54 months in hours per day on week and weekend days (Tables 5.23 and 5.24). A total TV viewing score in hours per week was derived by multiplying weekday hours by five and weekend day hours by two and summing the total.

Time watching TV (38 months)

"How much time on average does she spend watching TV:

*On most weekend/weekdays**

Possible responses: *Not at all, less than 1 hour per day, 1-2 hours per day, more than 2 hours per day*

*Derived variable for whole week = (5 x weekday score) + (2 x weekend day score)"

Time watching TV (54 months)

*"How much time on average does she spend each day:(i) on a weekday (ii) on a weekend day**

Possible responses: *Not at all, less than 1 hour per day, 1-2 hours per day, more than 3 hours per day*

*Derived variable for whole week = (5 x weekday score) + (2 x weekend day score)"

Table 5.23 TV viewing at 38 months

Hours per week	Frequency	Percent	Cumulative percent
0	169	1.2	1.2
1	37	0.3	1.4
2	6	0.0	1.5
2.5	141	1.0	2.5
3.5	1774	12.4	14.8
4	2	0.0	14.8
4.5	698	4.9	19.7
5	17	0.1	18.9
6	666	4.6	24.5
6.5	30	0.2	24.7
7	3149	22.0	46.6
9	752	5.2	51.9
10	5	0.0	51.9
11	49	0.3	52.3
12	492	3.4	55.7
14	1966	13.7	69.4
Missing	4390	30.6	100.0
Total	14343	100.0	

Percent totals may not add up due to rounding. Some percentages 0.0 due to rounding

Table 5.24 TV viewing at 54 months

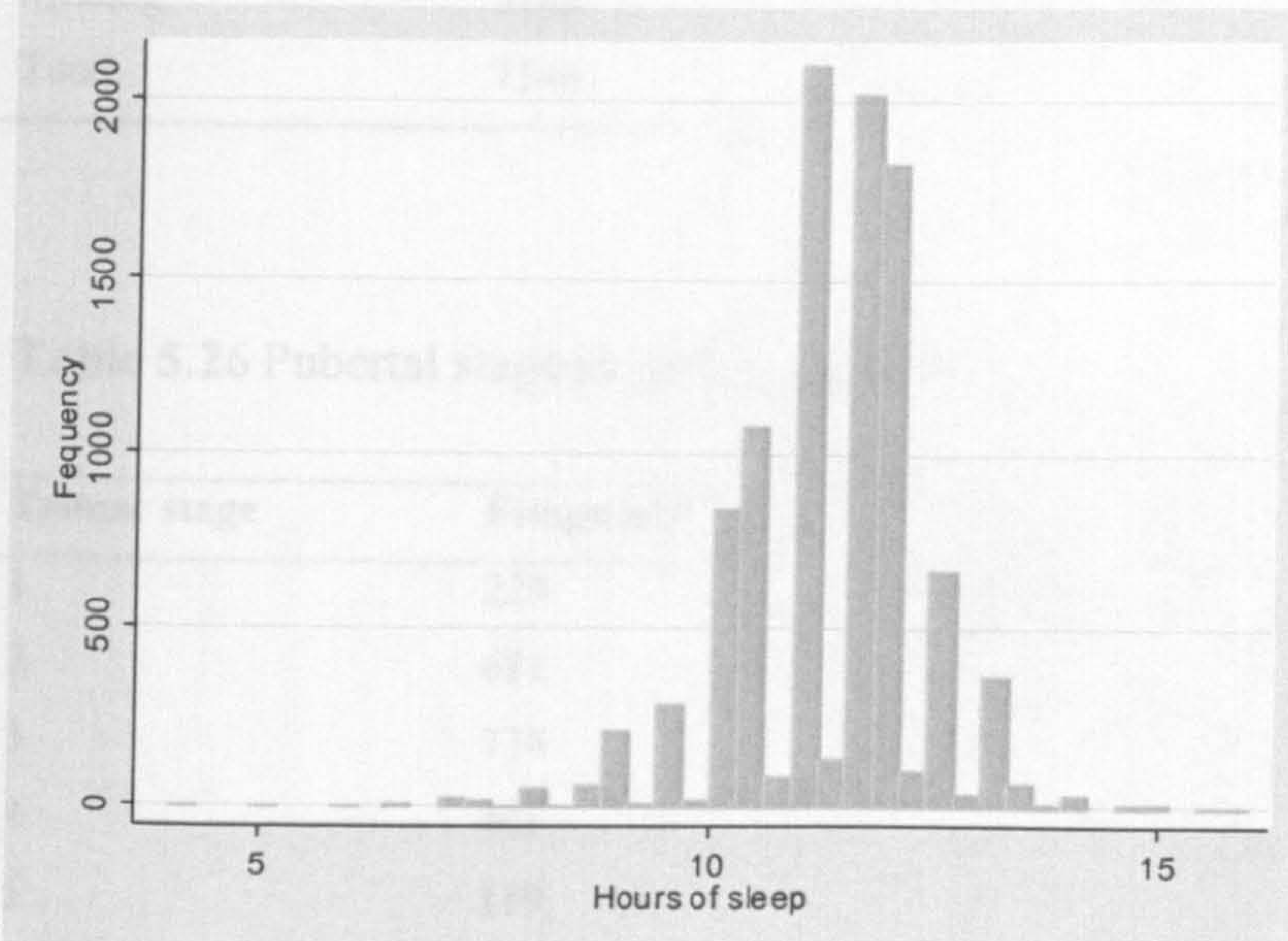
Hours per week	Frequency	Percent	Cumulative percent
0	77	0.5	0.5
1	42	0.3	0.8
2.5	44	0.3	1.1
3.5	976	6.8	7.9
6	1252	8.7	16.7
8	2	0.0	16.7
8.75	10	0.1	16.8
9.75	406	2.8	19.6
10.5	78	0.5	20.1
12.25	3420	23.8	44.0
16.75	1659	11.6	55.5
20	2	0.0	55.5
21	12	0.1	55.6
23.5	182	1.3	56.9
28	1207	8.4	65.3
Missing	4974	34.7	100.0
Total	14343	100.0	

Percent totals may not add up due to rounding. Some percentages 0.0 due to rounding

Duration of night-time sleep was recorded in the 30-month questionnaire (Figure 5.16). The mother was asked at what time the child normally went to bed at night and woke up in the morning. From this the number of hours per night the child usually slept was calculated.

Figure 5.16 shows an uneven distribution, which is probably due to digit preference in the respondents' answers i.e., rounding or choosing even numbers when answering the question.

Figure 5.16 Hours of night time sleep at 30 months



N=10059
Missing =4284
Mean (SD) 11.2 (1.0)
Median (IQR) 11.5 (10.5, 12.0)

5.2.6 Variables measured at 11 years

Pubertal status was derived from a Tanner stage questionnaire [158] completed when the child was about 11.8 years old and analysis was restricted to those who completed it within 16 weeks of the 11 year clinic measurements. Girls were classified according to Tanner stage based on most advanced breast and pubic hair development, and boys based on pubic hair development alone. Boys reporting a Tanner stage of 5 were excluded, as it was felt that no boys would have reached that stage of maturity at age 11 years. Tables 5.25 and 5.26 show the distributions of pubertal stage for boys and girls separately. BMI at age 11 years was calculated by dividing weight (kg) by height (m^2). Height was measured with shoes and socks removed using a Harpenden stadiometer (Holtain Ltd, Pembs, UK). Weight was measured using a Tanita TBF 305 body fat analyser and weighing scales (Tanita UK Ltd, Middlesex, UK). Figure 5.17 shows the distribution of BMI. Table 5.27 summarises all the variables used in this thesis.

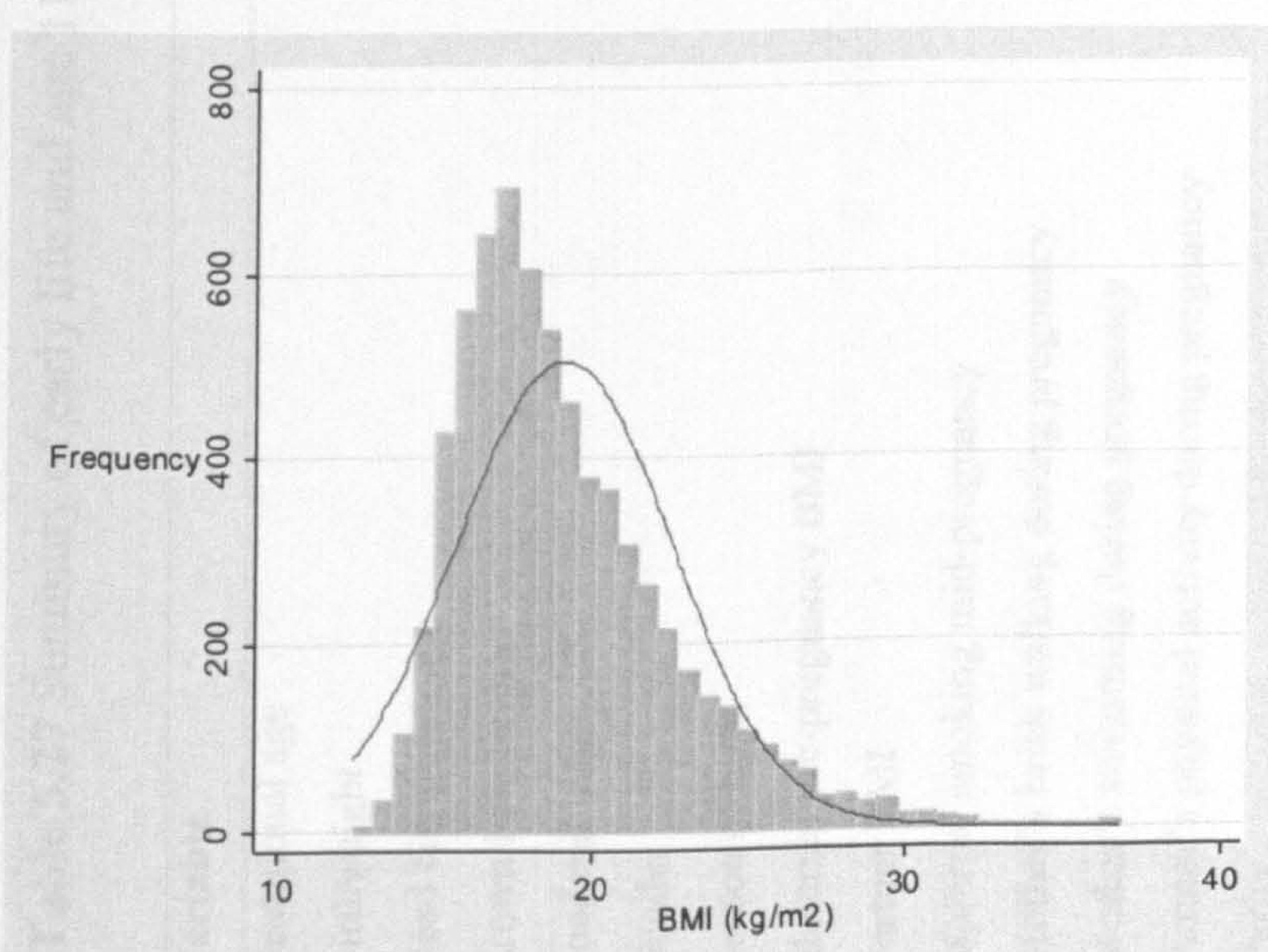
Table 5.25 Pubertal stage in boys at age 11 years

Tanner stage	Frequency	Percent	Cumulative percent
1	627	8.5	8.5
2	641	8.7	17.3
3	225	3.1	20.3
4	61	0.8	21.2
Missing	5283	71.9	100.0
Total	7346	100.0	

Table 5.26 Pubertal stage in girls at age 11 years

Tanner stage	Frequency	Percent	Cumulative percent
1	224	3.2	3.2
2	681	9.8	13.1
3	774	11.2	24.2
4	401	5.8	30.0
5	119	1.7	31.8
Missing	4727	68.3	100.0
Total	6926	100.0	

Figure 5.17 BMI (kg/m^2) at age 11 years



N=6990
Missing =7353

Mean (SD) 19.1 (3.4)
Median (IQR) 18.3 (16.6, 20.9)

Table 5.27 Summary of early life and age 11 variables in ALSPAC

Variable	Age collected	Type of variable	N
Gestational age	Birth	Continuous (weeks)	13978
Birthweight	Birth	Continuous (g)	13798
Head circumference	Birth	Continuous (cm)	10693
Crown-heel length	Birth	Continuous (cm)	10535
Ponderal index	Birth	Continuous (kg/m^3)	10418
Gender	Birth	Categorical	13972
Season of birth	Birth	Nominal	14618
Maternal pre-pregnancy BMI	12 weeks gestation	Continuous (kg/m^2)	11535
Partner BMI	12 weeks gestation	Continuous (kg/m^2)	8340
Maternal smoking mid-pregnancy	18 weeks gestation	Categorical	13311
Mother's brisk walking during pregnancy	18 weeks gestation	Categorical	12085
Mother's swimming during pregnancy	18 weeks gestation	Categorical	11970
Partner's physical activity during pregnancy	18 weeks gestation	Categorical	9963
Parity	18 weeks gestation	Categorical	13089
Partner smoking during pregnancy	18 weeks gestation	Categorical (yes/no)	12945
Maternal smoking end-pregnancy	32 weeks gestation	Categorical	11401
Mother's education	32 weeks gestation	Categorical	12101
Social class	32 weeks gestation	Categorical	11486
Partner's education	32 weeks gestation	Categorical	11627
Mother's age at birth of child	Enrolment	Continuous (years)	14081
Partner's age at birth of child	Enrolment	Continuous (years)	11780

Table 5.27 Summary of early life variables in ALSPAC, continued

Variable	Age collected	Type of variable	N
Activity score	6 months	Continuous	10502
Coordination score	6 months	Continuous	11077
Breast feeding	6 months	Categorical	11311
Presence of partner	8 months	Categorical	11279
Mother's physical activity	21 months	Categorical	10283
Partner's physical activity	21 months	Categorical	6145
Time outside	24 months	Categorical	10320
Duration of night-time sleep	30 months	Continuous	10059
Time outside	38 months	Categorical	9912
Time outside (summer)	54 months	Categorical	9360
Time outside (winter)	54 months	Categorical	9345
Time spent watching TV	38 months	Categorical	9953
Time spent watching TV	54 months	Categorical	9363
Pubertal stage (boys)	11 years	Categorical	2012
Pubertal stage (girls)	11 years	Categorical	2974
BMI	11 years	Continuous	6990

Chapter 6. Physical activity methods

6.1 Introduction

This chapter describes how data were collected for the main physical activity study at the 11-year ALSPAC data collection and also the methods for the two calibration studies. Some of the protocol and validity decisions were made based on the experience of other groups [62] before the data presented here were analysed and some were necessary to fit around the data collection procedures of ALSPAC. For example, the method of giving out the monitors needed to fit into the ALSPAC clinic schedule and protocols. The longitudinal nature of the study also meant that it was important to reduce subject attrition in order to maintain statistical power. Other studies with different designs (e.g. intervention studies) and sample sizes may have different requirements. The methods presented here may not be suitable for some studies and the results will not be informative in all circumstances.

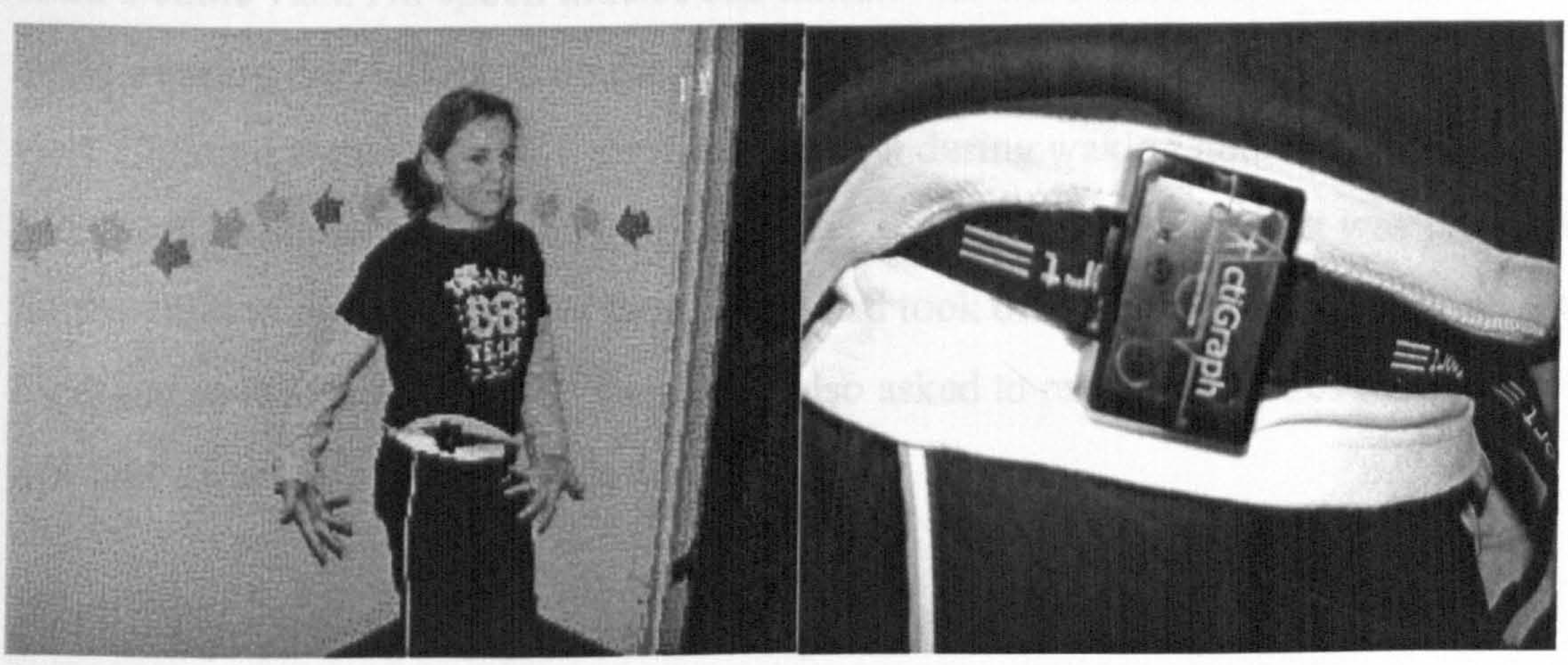
This chapter contains sections on the following:

- Selection of measurement instrument
- Physical activity measurement protocol including clinic protocol and handling of instruments
- Management of physical activity data including data cleaning and validity of data
- Methodology for the two sub-studies

6.1.1 Selection of measurement instrument

Accelerometry-based physical activity monitors have become increasingly popular as an objective method of assessing physical activity. There are a number of commercially available monitors that work using the same principles but the Actigraph (formerly known as the Computer Science and Applications - CSA) monitor, produced by Actigraph, LLC, Fort Walton Beach, Florida is the most widely used [59] (see Figure 6.1). The Actigraph has been discussed in more detail in Section 2.3.2.3 The Actigraph is a uni-axial accelerometer that uses a piezoelectric lever to detect acceleration ranging from 0.05 to 2.13G. As the subject moves, the lever bends and a signal is generated in proportion to the amount of acceleration, thus intensity of movement is recorded. The signal is sampled 10 times per second and the values summed over a user-specified 'epoch' [60]. The internal clock in the Actigraph allows time and duration as well as intensity of activity to be monitored, thus daily patterns of physical activity can be described [59] with substantially increased precision in comparison to self-report methods [59]

Figure 6.1 The 7164 Actigraph



Actigraphs have been used in studies on both adults and children, including a large, cross-sectional field study - the European Youth Heart Study [62] and more recently in the US [63]. The Actigraph has been calibrated in both children and adolescents against heart rate telemetry, [159] indirect calorimetry [2,160] observational techniques [161] and energy expenditure measured by doubly labelled water [64]. Ekelund *et al.* assessed the Actigraph in free-living children within the European Youth Heart Study using energy expenditure measured by doubly labelled water as the criterion measure. Accelerometer output (counts) was related to physical activity level (PAL - an index of activity level; total energy expenditure/ basal metabolic rate. $r = 0.58$, $P < 0.01$) [64]. The Actigraph has been shown to be valid and reliable in children, with a between instrument correlation of 0.87 being reported [65]. The same study reported correlations of 0.86 and 0.87 (one on each hip - $P < 0.001$) between activity counts and energy expenditure measured by indirect calorimetry [65].

6.2 Physical activity measurement protocol

6.2.1 Focus 11 clinic protocol

All children who attended the ALSPAC study clinic at age 11 were asked to wear an Actigraph for seven days. Actigraphs were normally initialised (using Actigraph Reader Interface Unit RIU-41A with RIU software version 2.26B, Actigraph, LLC, Fort Walton Beach, Florida) to start recording at 5am on the day following each child's clinic visit. An epoch time of one minute was used. The child was asked to begin wearing the Actigraph on the right hip on the morning following their clinic visit. Children were asked to wear the Actigraph during waking hours and only to take it off for showering, bathing or any water sports. A daily timesheet was provided for the child to record the times they put on and took off the Actigraph and the reason for doing so (see Appendix 8). They were also asked to record any times (in minutes) that they swam or cycled each day.

Clinic reception staff, who perform a number of roles in the clinic, including interviewing families, were trained by Research Assistants (including the author) from the physical activity team in the correct procedure for recruiting volunteers and demonstrating to children how to wear the Actigraph. Receptionists emphasised the voluntary nature of the study but also stressed the importance of compliance to the protocol, correct positioning of the Actigraph and the need for Actigraphs to be returned immediately following the study period. Explaining the procedure to the child and parent took between five and 10 minutes.

The protocol was explained and verbal consent was obtained from the child and the carer. To demonstrate the correct positioning of the Actigraph, children were shown how to attach it in the clinic using the elastic belt and were instructed that the instrument should be worn on the right hip and that the fitting should be 'snug', i.e. not so tight that it caused discomfort and not so loose that it moved independently of the body. There was also a 'demonstration' Actigraph with the back cover taken off so that the children could see what was inside.

Children were asked to post the Actigraph back on the day after their final day of wearing it. They were also told that they would be sent a certificate showing how active they had been on the first day of wearing the Actigraph (Appendix 7). Those who agreed to take part were given an 'activity pack' to take away which included the following:

- A daily timesheet for the child to record the times they put on and took off the Actigraph and the reason for doing so. They were also asked to record any times (in minutes) that they swam or cycled each day (Appendix 8)
- Separate written instructions for the parent and child along with a telephone number to contact in case of queries or problems (Appendix 9)
- A 'carry card' to take to school explaining what the Actigraph was for and why they were wearing it (Appendix 10)
- A stamped, addressed, padded envelope to return the Actigraph

A reminder card was automatically generated on each child's second day of recording and posted to arrive on the penultimate day of recording. Failure to return the Actigraph was followed up by a phone call after approximately three weeks and a follow-up letter was sent approximately four weeks after the phone call.

Each child was given a £5 gift token for attending the 11-year clinic.

6.2.2 Data handling

Returned Actigraphs were downloaded using the Actigraph Reader Interface Unit and software. The raw data were then imported using customised software into a Microsoft™ Access 2000 database. The software produced a series of derived variables describing levels and patterns of physical activity (see Table 6.1). The main outcomes used were counts per minute – an estimate of total physical activity i.e., volume of physical activity, and minutes of MVPA. The total time (minutes) of MVPA recorded was divided by the number of valid days recording, giving an average number of min/day across the measurement period. This was considered to be more valid than scrutinizing each individual day as this would disadvantage children who achieved well in excess of 60 min on one day followed by a marginal failure to achieve 60 min on another. Cut-points for moderate and vigorous physical activity (≥3600 and ≥6200 counts per minute, respectively) were derived from a calibration study of 246 children (see section 6.3.2) where Actigraphs counts per minute were compared with oxygen uptake [2]. The sedentary cut-point was similar to that used by Treuth *et al.*[162] who defined sedentary as <50 counts per 30 seconds. The software used in this study derived categories of physical activity intensity in blocks of 200 counts/ minute so sedentary was defined as 0-199 counts per minute.

Instruments were calibrated with every battery change – about every 6 months. Over the two-year data collection period, 267 instruments were used (acquired in batches over the study period) and of these, approximately 15 developed faults during the course of the study. Five hundred and eighteen calibrations were carried out according to manufacturers specifications. Of the 518 calibrations, 394 (77%) required no adjustment.

Table 6.1 Variables derived from the raw Actigraph data

Variable	Explanation
Start time	Time Actigraph was put on each day
End time	Time Actigraph was taken off each day
Battery life	Battery life remaining on monitor
Counts	Total number of counts per day
Minutes	Total number of minutes per day
Counts Per Minute	Counts per minute for each day
No. of minutes spent in each PA intensity category	Total number of minutes per day spent at each intensity category per day. Range from 0-199 to 8000+ counts in intervals of 200
Sedentariness	Daily number of 30 minute bouts of sedentariness
Bouts >5	Daily number of 5 minutes bouts of moderate to vigorous MVPA per day
Bouts >10	Daily number of 10 minutes bouts of MVPA
Bouts >20	Daily number of 20 minutes bouts of MVPA
Number of counts per minute per hour each day	Average counts per minute during that hour on each day. Range from 0-1am to 23-24pm in 1-hour intervals

Sedentariness defined as ≤199 counts per minute
MVPA- moderate to vigorous physical activity; defined as ≥3600 counts per minute [2] (see section 6.3.2)

6.2.3 Data management and cleaning

A number of decisions were made to define what constituted "valid" data. Some of these were based on previous studies and some were based on estimates of reliability and power in this study. When the macro encountered ten or more minutes of consecutive zeros, these were regarded as periods where the monitor was unworn and these were deleted from each file [62]. This was done to prevent "dilution" of time spent in higher intensity activities by including times when the monitor was not worn during any day. If on any one day the average counts per minute was less than 150 or the average counts per minute was more than 3 SDs above the mean [163] this day was excluded as it was considered that this level of physical activity was behaviourally implausible. In the K4 sub-study [2] (see Section 6.3.2) the children were asked to "walk briskly" while wearing an Actigraph (mean walking speed 5.8 kph). Counts per minute ranged from 1816-7136. The mean plus 3 SDs before removal of spurious data was 1665 counts per minute and it is unlikely that a child could sustain this level of intensity for an entire day. Also, as part of the same calibration study children were asked to lie still for 5 minutes and then to sit still for five minutes while wearing an Actigraph. Although 88% of children managed to lie still enough to accrue no counts and 77% managed to sit still enough to accrue no counts, six children accrued between 60-100 counts per minute for lying or sitting. It is unlikely that many children could maintain a level of average activity below 150 counts per minute over an entire day. A day was considered as valid if the monitor was worn for at least 600 minutes. This allowed comparison with other similar studies e.g., EYHS [62].

6.3 Methods for sub-studies

6.3.1 Introduction

Two sub-studies that relate to the main physical activity study form part of this thesis. The first was a calibration study designed to develop an equation to predict energy expenditure and to derive cut-points for moderate and vigorous physical activity (K4 study). The second sub-study was a repeat measures design, which is intended to describe the variability and seasonality of physical activity in a sub-sample of ALSPAC children. Both of these sub-studies were carried out concurrently with the main study.

6.3.2 K4 sub-study

The K4 sub-study (named after the Cosmed K4 O_2/CO_2 analyser used – see Figure 6.3) is published as "Calibration of an accelerometer during free-living activities in children" [2] (see Appendix 2). Children who volunteered for the sub-studies (n= 1595, see also section 6.3.3) were randomly selected for the K4 study. Those who were selected (N=452; more were selected than were expected to agree to participate. The target sample size was approximately 240) were stratified into four groups according to gender and body mass index (BMI) (BMI below or above the medians of 17.6 kg/m^2 for boys and 18.8 kg/m^2 for girls) in order to ensure a balance between gender and body size in the sample. Equal numbers of children were randomly selected from each of these strata and invited to participate in this study. An invitation letter was sent to the selected children, along with a detailed information sheet that explained the nature of the study.

Children who agreed to participate were contacted by telephone and a study appointment made. The children were asked not to eat or drink for at least one hour prior to their visit and to wear clothing appropriate for exercise. Children were accompanied by a parent, and were asked to respond verbally to questions from a modified physical activity readiness questionnaire (PAR-Q) [164] to confirm their suitability to participate. The test protocol was explained and parents gave written informed consent while children gave written assent. Height was measured to the nearest 0.1cm (Leicester Height Meter, Invicta Plastics, Leicester, UK) and weight to the nearest 0.1kg (Seca 770, Hamburg, Germany). BMI was calculated by dividing weight (kg) by height (m) squared. Children were then fitted with the Actigraph and a portable metabolic unit (Cosmed K4b^2. Cosmed, Rome, Italy) and were given approximately five minutes to become familiar with wearing the equipment. Those who participated were given a £10 gift token and a Polaroid photograph of themselves wearing the K4.

Figure 6.2 Activities with the Cosmed K4

The Cosmed K4b^2 measures breath-by-breath ventilation (V_E), fraction of expired oxygen ($F_E O_2$) and carbon dioxide ($F_E CO_2$). The unit weighs 1.5kg and is held in a chest harness. Expired gases are collected via a mask and sampled by O_2 and CO_2 analysers. The instrument was calibrated in accordance with the manufacturer's instructions. The Cosmed K4b^2 has been validated in children with small, positive biases in VO_2 of less than 6% during walking and running reported [165].

The exercise tests were performed indoors. Children were asked to perform six activities, each of which lasted for five minutes. Table 6.2 describes these activities in the order they were carried out. The activities were selected to provide graded increases in intensity and to reflect the type of locomotor activities that comprise the majority of children's activity [166]. Hopscotch was included to simulate a sporadic jumping, bending and stretching type of activity. Apart from lying and sitting, all activities were self-paced in order to better reflect free-living conditions. Walking and jogging activities took place around an indoor jogging track. Lying and sitting were on a bench with an exercise mat to lie on at the side of the jogging track. Children progressed through the activities without stopping apart from the hopscotch activity. Walking and jogging speeds were calculated by using markers every 5m on the jogging track and calculating speed from distance travelled and the length of time taken. The Cosmed K4 recording was also "marked" electronically by a Research Assistant whenever the activity changed.

In addition, the children also wore an Actiheart, which is a combined accelerometer and heart rate monitor designed to overcome some of the problems that are encountered when using either method alone. The Actiheart has been developed at the University of Cambridge and is used by a group at the MRC Epidemiology Unit in Cambridge. This study does not form part of this thesis but has already been published in a collaboration between the ALSPAC physical activity team and the University of Cambridge [167].

Table 6.2 Descriptions of physical activities performed by the children

	Activity	Description
1	Lying	Child lay on a gym mat on a bench with a pillow
2	Sitting	Child sat on the bench and played a hand-held video game
3	Slow walking	Child walked at own pace but told to "walk slowly"
4	Brisk walking	Child walked at own pace but told to "walk briskly"
5	Jogging	Child jogged at own pace
6	Hopscotch	Child played hopscotch at own pace

Data from the Actigraph were imported into an Excel spreadsheet using the Actigraph Actisoft software. Data for each test from the Cosmed K4 unit were downloaded using the manufacturers' Data Management Software version 7.3a at the end of each test and subsequently imported into an Excel spreadsheet. Data from both the Actigraph and the Cosmed spreadsheets were then imported into an Access database using a customised macro. The macro summed the Actigraph counts from minutes 3 ½ to 4 ½ (i.e. the total of six 10 second epochs) for each activity in order to allow oxygen uptake to stabilise. This was matched with the mean of the corresponding minute of the K4 data. The data from the remaining 4 minutes were not used. Half minutes were used to avoid any change in counts or oxygen uptake as children changed from one activity to the next. Energy expenditure ($kJ \cdot kg \cdot min^{-1}$) was calculated from VO_2 using the Weir formula [168] divided by weight (kg).

6.3.3 Four seasons sub-study

The Four Seasons sub-study is published as "Intra-individual variation of objectively measured physical activity in children" [3] (see Appendix 3). This was a repeat measures study where a sub sample of children who had successfully worn the Actigraph at the 11 year clinic were asked if they would be willing to take part in an unspecified further study. This group was used to randomly select children to one of three sub-studies. These were the Four Seasons, the K4 and an MRI scan study that will not be discussed in this thesis. Of those who were willing to take part in a sub-study (n=1595) and who had successfully worn the Actigraph on the initial occasion, 548 were randomly selected for inclusion in the Four Seasons study. Participants were contacted approximately three months after the first occasion of wearing the Actigraph and a date was agreed for them to wear it again for seven days. The Actigraph, along with instructions, a return envelope and a timesheet to record when the Actigraph was put on and taken off were posted to them. This was repeated twice more so that children wore the Actigraph a total of four times over the course of a year, once in each season. Initialising and downloading Actigraphs and checking and cleaning data were all done using the same protocol as the main study (see section 6.2). Children were given a £5 gift token for attending the 11-year clinic and another £5 token for each subsequent time they wore the Actigraph apart from the final occasion when they received £10.

6.3.4 The author's role in the data collection

As leader of the physical activity team, the author's role was to oversee data collection of the main study (the data collection in the 11-year clinic and also subsequent clinics at ages 13 and 15) and also both sub-studies. Each clinic takes approximately 18 months to complete so the next one starts as the previous one finishes. During the 11-year clinic, almost 100 Actigraphs per week were initialised, given out to children and downloaded. For the Four Seasons study, volunteers were recruited and added to a database so that they could be sent an Actigraph a further three times. This ongoing process took about a year and required initialisation and downloading of approximately a further 1000 Actigraphs. For the K4 study the author set up piloting the protocol, trained staff and took part in the data collection. Again, it took about one year to see almost 260 children.

6.4 Summary

- Children attending the ALSPAC 11 year clinic were asked to wear an Actigraph for seven days

- A calibration study designed to develop cut points for MVPA was carried out on a sub-sample of children

- A repeat measures study was carried out over a one year period to assess the variability and seasonality of physical activity in a sub-sample of children

Chapter 7. Statistical methods

7.1 Introduction

Dr Sam Leary of the Department of Social Medicine and the author carried out statistical analyses jointly. The author conducted all the analyses for the Determinants study (see Section 7.2.5) and all the analyses for the Descriptives study (see Section 7.2.4) apart from the physical activity/ BMI analysis, which was not included in this thesis. Analyses for the Methods (see Section 7.2.1) study were carried out jointly by Dr Leary and the author. Analyses for both sub-studies (K4 and Four Seasons -see Sections 7.2.2 and 7.2.3) were carried out by Dr Leary initially, and then the author repeated much of the analysis after resubmitting the chapters as papers, following reviewer's comments.

All statistical analyses were carried out using Stata Version 8.0 for Windows (Stata Corporation, College Station, Texas). All analyses (except for the K4 study) were repeated excluding those children who reported any swimming or cycling during the time they wore the Actigraph. This is because the Actigraph doesn't measure the activity of cycling well and it can't be worn during swimming.

This chapter will discuss the following:

- Distributions, data checking and summary statistics
- Statistical methodology for Methods study
- Statistical methodology for K4 sub-study
- Statistical methodology for Four Seasons sub-study
- Statistical methodology for Descriptives study
- Statistical methodology for Determinants study
- Summary

7.1.1 Distributions, data checking and summary statistics

Histograms with superimposed normal curves were used to check for normality of continuous data, and a subjective decision was made whether a transformation was needed so as not to violate the assumptions of linear regression techniques. As the samples used are relatively large and the skewness often not marked, the data were transformed only in some cases. For the Determinants study, robust standard errors were used. Robust standard errors allow derivation of confidence intervals and standard errors based on the actual distribution of the outcome variable in the dataset, rather than on an assumed underlying probability distribution [169]. For categorical data, frequency tables were produced.

7.1.2 Data checking

Range checks and logical checks were used to look for extreme or biologically implausible values. For the main physical activity data set (used for the Methods, Descriptives, Determinants and Four Seasons studies) outliers were excluded from the analyses. See section 6.2.2 for a fuller discussion.

7.1.3 General statistical tests used

T-tests and chi-squared tests were used to test for differences between continuous variables and categorical variables, respectively. Where the outcome was categorical, the analysis of variance (ANOVA) test was used. Linear regression was the main test used for examining associations where the outcome was a continuous variable e.g., physical activity. In each of the chapters, other tests specific to the analysis being undertaken were used. These are discussed in each of the sections pertaining to these chapters (see Section 7.2).

7.1.4 P values and significance

All P values are reported to three decimal places so that P<0.001 is the smallest P value reported. The commonly used P<0.05 threshold of statistical significance is not used due to the arbitrariness of accepting or rejecting an association as meaningful on this basis [130].

7.2 Statistical methodology for individual studies

7.2.1 Statistical methodology for Methods study

The analyses here refer to the Methods paper "Use of accelerometers in a large field based study of children: protocols, design issues and effects on precision." [1] (see Appendix 1). Means and standard deviations were calculated for continuous variables and proportions were calculated for categorical variables. Differences between continuous variables were tested using t-tests and Analysis of Variance (ANOVA) and differences between categorical variables were tested with chi-squared tests. The number of days of monitoring and the number of minutes per day required to achieve reliabilities of 0.7, 0.8 and 0.9 were calculated using the Spearman-Brown prophecy formula [170], which uses the intraclass correlation coefficient (ICC) as a measure of reliability. The ICC is defined as the ratio of between individual variance to the sum of the between and within individual variance [170]. The ICC for a single day of monitoring was calculated from formula [1] where σ_b^2 is the between individual variance and σ_w^2 is the within individual variance [38].

$$ICC_s = \sigma_b^2/(\sigma_b^2 + \sigma_w^2) \qquad [1]$$

The formula for estimating the number of days of measurement to achieve a specified reliability is shown in equation [2], where N is the number of days required to achieve ICC_t, the desired reliability and ICC_s is the single day ICC from equation [1].

$$N = [ICC_t/(1 - ICC_t)][1 - ICC_s/ICC_s] \qquad [2]$$

Power to detect a difference of 0.07 SDs – about 12 counts per minute ($p \leq 0.05$) in counts per minute between any two groups was also calculated for various combinations of numbers of days of measurement and hours per day. To test for instrument reactivity a linear regression model that specifically allowed for clustering in the data was used to examine associations between total activity and day of measurement. The "cluster" option was used with the "regress" command in Stata to specify that the observations were independent across groups (i.e. individuals) but not within groups. This allows for repeated observations on individuals without violating the assumption of independence in the data [171].

7.2.2 Statistical methodology for K4 sub-study

The methodology presented here refers to "Calibration of an accelerometer during free-living activities in children" [2] (see Appendix 2). Means and standard deviations were calculated for normally distributed variables and medians and interquartile ranges (IQRs) for skewed variables, and percentages for categorical variables. Pearson correlation coefficients were used to assess relationships between normally distributed continuous variables.

7.2.2.1 Prediction of energy expenditure

Sixty-six percent (n=163) of the children were randomly selected to create a developmental group. The equation for predicting energy expenditure from counts per minute was derived using a random intercepts model. A random slopes model was initially tried but the slopes did not vary sufficiently. The model was fitted with and without adjusting for potential confounders age and gender. Backwards elimination was used to see if either of the potential confounders could be removed. The remaining children were allocated to the validation group (n=83). The validity of the equation was assessed by calculating limits of agreement [172] for actual and predicted energy expenditure (mean difference +/- 2 SDs of the difference, with the difference calculated as actual- predicted energy expenditure). Limits of agreement were also calculated in the developmental group for comparison.

After validation of the equation, all remaining analyses were undertaken on the developmental group only. From the prediction equation, residuals were calculated, their distribution checked for normality, and they were plotted against predicted values, to ensure the model fitted adequately.

7.2.2.2 Derivation of activity intensity cut-points

The prediction equation, with and without confounders, was then refitted using VO_2 as the outcome instead of energy expenditure, in order to derive threshold values of counts per minute for moderate (three and four METs) and vigorous (six METs) intensity. For moderate intensity, cut-points were derived for both three and four METs. Three METs was included to allow for comparison with other studies. However, there is evidence that four METs is a more appropriate cut-point. Treuth *et al.* found that girls with a mean age of 14 were working at the lower end of 40-60% VO_{2max} (which defines moderate intensity activity) and that this was equivalent to 4.3 METs during brisk walking at 3.5mph (5.6kph) [162]. This is similar to our mean self-selected brisk walking speed of 5.8kph. Similarly, Harrell *et al.*, in children of a similar age, report that walking at 5.6kph elicits 4.3- 4.7 METs [165].

The conversion of one MET = baseline VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$); the minimum of lying or sitting VO_2 was taken for each child, and the mean for all children used as the baseline. When confounders were included in the equation, they were centred to allow predictions to be made for the 'average' child. Cut-points were calculated for the whole developmental group (with and without confounders), and males and females separately. Sensitivities and specificities based on children in the validation group were also calculated from the resulting threshold values, using the VO_2 MET values as the gold standard.

7.2.3 Statistical methodology for Four Seasons sub-study

The methodology presented here refers to Four Seasons sub-study, "Intra-individual variation of objectively measured physical activity in children" [3] (see Appendix 3). The main outcome measure was counts per minute which has previously been validated against doubly-labelled water [173]. Additional outcomes examined were weekday and weekend counts per minute, minutes of MVPA, minutes of vigorous physical activity, minutes of sedentary behaviour and blocks of sedentary behaviour lasting 30 minutes or more. All outcome variables had skewed distributions, so log transformations were used.

T-tests and tests for proportion were used to test for differences based on data from up to four measurement occasions per child. The ICC was calculated from this as the aim was to estimate variation over a year [174]. Initially the model was fitted with no fixed effects. Then, a forwards stepwise procedure was used to decide which of the possible confounders (gender, height, BMI and age) were required. The selected variables were centred before being added to the model as fixed effects, to allow calculation of predicted mean values. Finally, month of measurement was also added to the model. As the relationship between logged counts per minute and month was not linear, sine and cosine functions of month were included as fixed effects in the model. Models containing different numbers of sine and cosine functions were compared to see which best fitted the data. For each of the three models (unadjusted, adjusted for potential confounders, adjusted for potential confounders plus functions of month) with logged counts per minute as the outcome, the mean, intra-individual standard deviation (SD), co-efficient of variation (CV; SD as a percentage of the mean) and ICC were calculated. As a log scale was used, the CV was calculated by taking the antilog of the intra-individual SD and subtracting one.

The analyses were repeated with pubertal status at baseline added to the final model. Analyses were also repeated with the measurement occasion excluded if any swimming and/or cycling were reported on that occasion (the Actigraph does not measure cycling activity well and swimming was chosen as a typical pursuit that would result in unrecorded physical activity). Analyses were repeated with weekdays of monitoring while the child was on school holidays excluded, and finally by restricting to children with data for all four measurement occasions only. The analyses for counts per minute and minutes of MVPA were repeated restricting the number of valid days on each measurement occasion to 3, 4, 5 days and 6 or 7 days combined, for children with data for all four seasons. Days 6 and 7 were combined due to low numbers so that the maximum of either 6 or 7 days was used. This meant that combinations of 6 and 7 days across 4 seasons were possible.

7.2.4 Statistical methodology for Descriptives study

The descriptives study refers to the paper "Objective measurement of levels and patterns of physical activity" [4] (see Appendix 4). This paper was intended to be a description of the levels and patterns of physical activity at age 11 in ALSPAC. At the suggestion of a reviewer, however, some analyses on the association of physical activity and obesity were added. For this thesis, only the main section regarding the patterns and levels of physical activity will be discussed, as the associations between obesity and physical activity do not form part of this thesis.

The median and the interquartile range (IQR) were calculated for all variables. Physical activity variables were moderately skewed therefore log transformations were carried out for testing between samples. Statistical tests were carried out on these transformed variables. Differences between groups were assessed using independent samples t-tests. A two-sample proportion test was used to test for group differences (participants v non-participants, boys v girls) in the proportions of children achieving recommended levels of activity. To establish whether there were differences in activity levels between children with different numbers of days of measurement, mean values of activity counts per minute were calculated separately for children with 3, 4, 5, 6, and 7 days of valid activity measurements. Differences between the groups with different numbers of valid days of measurement were assessed using one way Analysis of Variance (ANOVA). The influence of season and social position on physical activity levels was assessed using multiple linear regression. For the regression analysis, data were not transformed but robust standard errors were used.

7.2.5 Statistical methodology for the Determinants study

The methodology presented here refers to the paper "Early life determinants of physical activity in 11-12 year olds: a cohort study" (see Appendix 5). A series of models were used to explore the possible role of confounders with counts per minute as the outcome. Model one was adjusted for age and gender. Model two was adjusted as model one plus confounding factors – i.e. factors that might be related to physical activity and the exposure variable or that might be more distal determinants of physical activity – maternal education and social class. Model three was adjusted for the confounders in model one but restricted to those with all available data from model two. Measures of size at birth were additionally adjusted for gestational age. Season of birth was additionally adjusted for season of measurement as all children were seen at about age 11 years and 9 months, so season of birth is likely to be related to season of measurement. Models were run separately for each exposure i.e., they were not mutually adjusted. The analysis for models one and two was repeated with minutes of MVPA as the outcome. The analyses were repeated in children who did not report swimming in the period of measurement and in children who did not report cycling in the period of measurement, as the Actigraph is not worn during swimming and the Actigraph does not record activity associated with cycling accurately. Analyses were carried out on boys and girls combined. To test for an effect modification of gender, interaction terms (gender*exposure variable) were introduced into model one. Where there was evidence of an interaction, the analyses were carried out separately for boys and girls. There was moderate skewness in the activity variables. For the analyses, data were not transformed but robust standard errors were used. Results for continuous variables are presented as standardised regression coefficients. Thus the regression coefficient for continuous variables is the difference in cpm associated with a one standard deviation change in the exposure variable. The results for categorical variables are presented as normal regression coefficients.

7.2.6 Summary

- This chapter presented an overview of the statistical methods used in this thesis and additionally, more detailed statistical methodology for each chapter

- My role and the role of others in the statistical analyses were outlined

- Statistical methods for producing distributions, summary statistics and data checking were outlined

- Statistical methods for the Methods study, both calibration sub-studies, Descriptives study and the Determinants study were described in detail

Chapter 8. Results section

8.1 Use of accelerometers in a large field based study of children: protocols, design issues and effects on precision

This section reports the results from the Methods paper (see Appendix 1 for paper and Section 6.1 for a description of the methods). This study was undertaken to address the uncertainties in the number of hours per day and total number of days of measurement required to characterise usual activity; compliance (and the resulting potential bias introduced by non-response); instrument reactivity (changes in activity resulting from wearing the instrument) and the potential for bias resulting from differences in number of days of measurement and different start days.

8.1.1 Subjects who wore the Actigraph at age 11

A total of 11,952 children were invited to come to the 11-year clinic, of whom 7,159 (60%) came for assessment and 6,622 (93%) agreed to wear an Actigraph (Figure 8.1). Some of the variables derived by the macro are summarised in Table 8.1.

Figure 8.1 Flow of physical activity study participants through the ALSPAC clinic

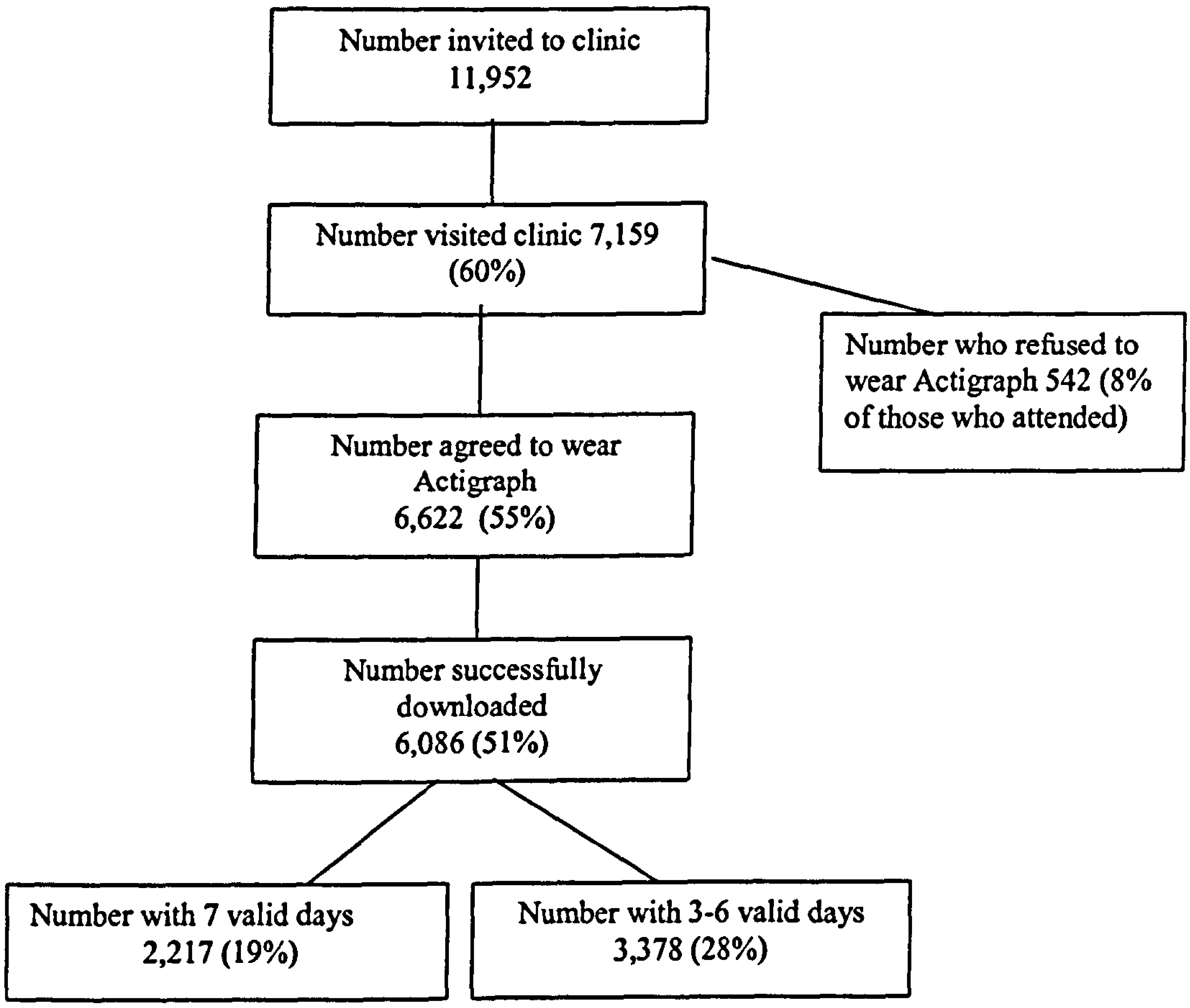


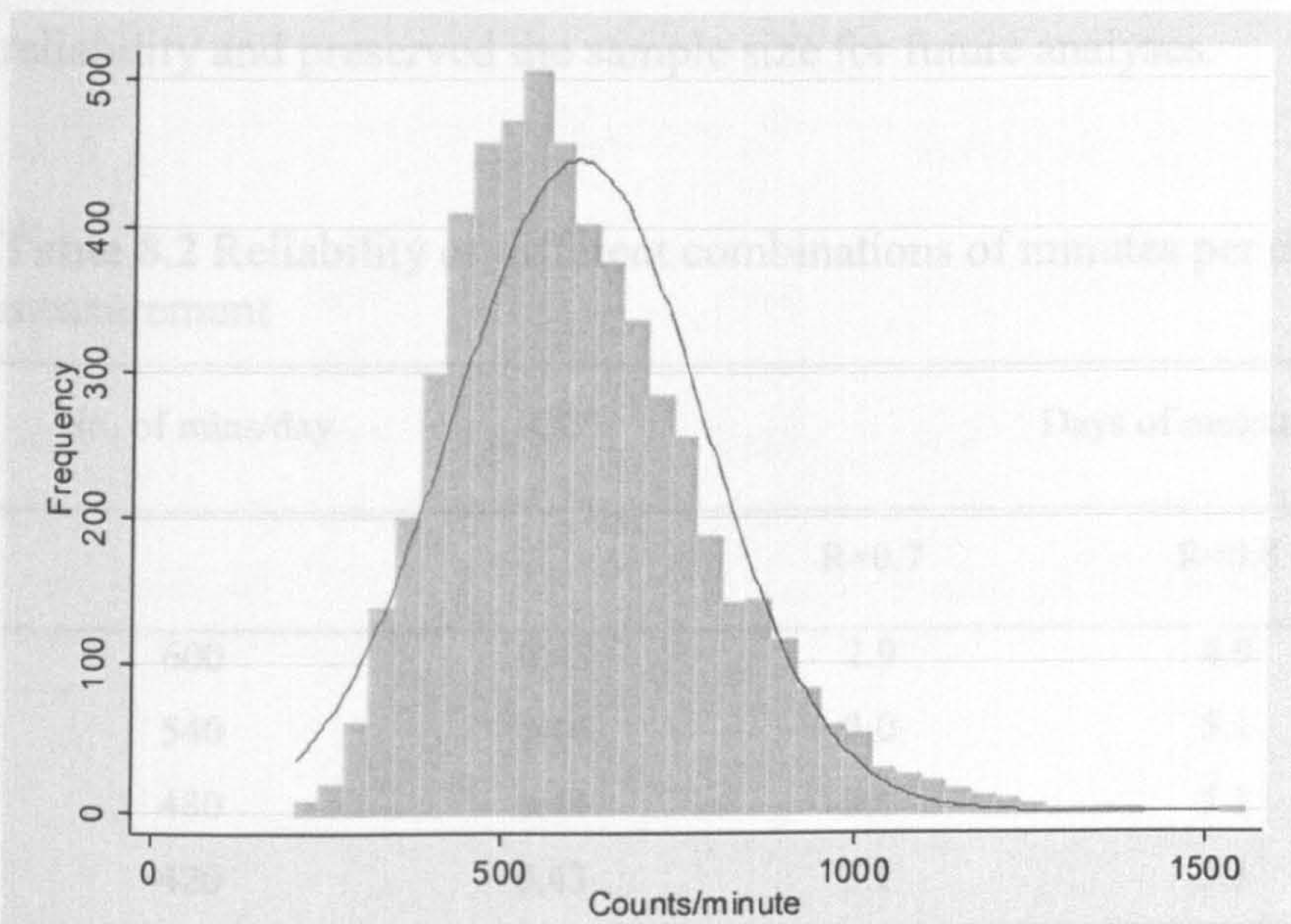
Table 8.1 Descriptive statistics of physical activity summary measures derived from raw data

Summary measure	Mean or median	SD or IQR	Range
Number of valid days	5.9	1.2	3-7
Total counts	2758408	993916	577701-7361597
Total minutes	4585	1026	1895-6777
Hours/weekday	13.1	0.9	10.0-18.3
Hours/weekend day	12.3	1.2	10.0-20.5
Counts per minute	604	178	204-1520
MVPA[a b]	19.7	11.7, 31.0	0.3-125.5
Number of bouts of 5-9 minutes of MVPA[a]	0.6	0.2, 1.3	0.0-6.4
Number of bouts of 10-19 minutes of MVPA[a]	0.0	0.0, 0.25	0.0-3.3
Number of bouts of ≥20 minutes of MVPA[a]	0.0	0.0, 0.0	0.0-1.3
Number of bouts of ≥30 minutes of sedentary[a c]	0.7	0.3,1.2	0.0-4.8

[a]Median. IQR= interquartile range
[b]MVPA- moderate to vigorous physical activity; defined as ≥3600 counts per minute
[c]Sedentary defined as ≤199 counts per minute

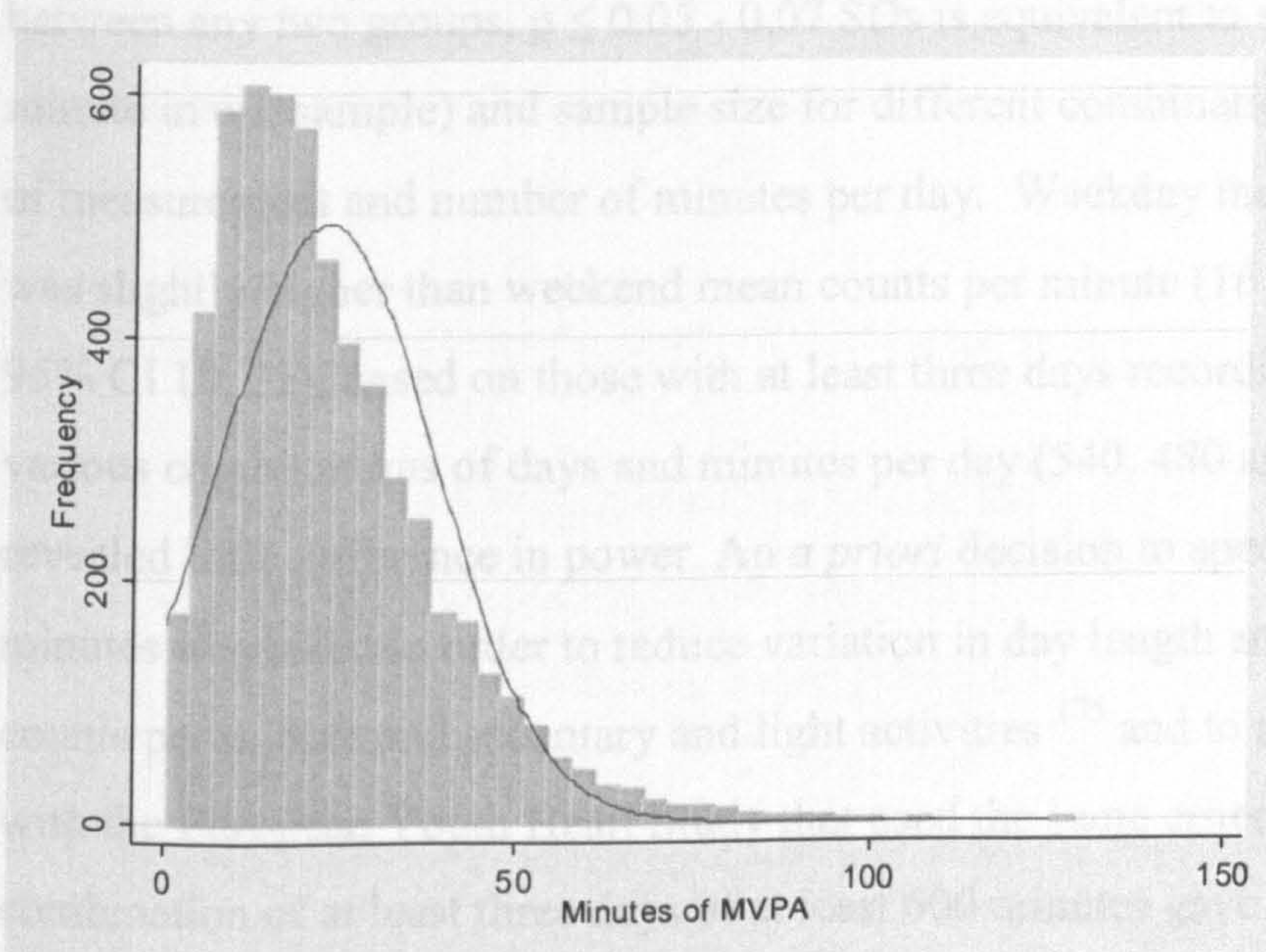
The main outcomes were counts per minute and minutes of MVPA. Figures 8.2 and 8.3 show the distributions for these outcomes for the sample used in the analyses for the Methods paper.

Figure 8.2 Histogram of counts per minute for valid sample



N=5595
Mean (SD) 604 (178)
Median (IQR) 580 (474, 710)

Figure 8.3 Histogram of minutes of MVPA for valid sample



N=5595
Mean (SD) 23 (15)
Median (IQR) 20 (12, 31)

8.1.2 Number of minutes and days of measurement

Table 8.2 shows the reliability co-efficients for different combinations of number of days and number of minutes per day. The single day ICC for 10 hours of measurement was 0.45. Single day ICCs (from equation [1]) for different numbers of minutes per day were similar. Increasing the number of days of measurement increased the reliability. Three days of recording was chosen as it gave reasonable reliability and preserved the sample size for future analyses.

Table 8.2 Reliability of different combinations of minutes per day and days of measurement

No. of mins/day	ICC[a]	Days of measurement[b]		
		R=0.7	R=0.8	R=0.9
600	0.45	2.9	4.9	11
540	0.44	3.0	5.1	11.5
480	0.44	3.0	5.1	11.5
420	0.43	3.1	5.3	11.9

[a]based on maximum number of valid days available. [b]predicted by spearman Brown prophecy formula. R = reliability. ICC= intraclass correlation coefficient (inter-individual variation/ total variation)

Table 8.3 shows power (to detect a difference of 0.07 SDs in counts per minute between any two groups, $p \leq 0.05$ - 0.07 SDs is equivalent to about 13 counts per minute in our sample) and sample size for different combinations of number of days of measurement and number of minutes per day. Weekday mean counts per minute was slightly higher than weekend mean counts per minute (16 counts per minute; 95% CI 10, 22), based on those with at least three days recording. Examination of various combinations of days and minutes per day (540, 480 and 420 minutes) revealed little difference in power. An *a priori* decision to specify a valid day as 600 minutes was taken in order to reduce variation in day length and its potential to affect counts per minute and sedentary and light activities [175] and to allow direct comparison with the European Youth Heart Study that used the same criterion [62]. This combination of at least three days of at least 600 minutes gave reasonable reliability (Table 8.2), power >90% (Table 8.3) and ensured a sufficient sample size for future analyses. Although a weekend day was not specified in order to fulfil validity criteria, 90% of children had at least one weekend day of recording.

Table 8.3 Power and sample size for different combinations of minutes per day and days of measurement

	Number of days							
	≥ 3 (any type)		≥3 (≥2 weekday+≥1 weekend)		≥ 5 (any type)		≥5 (incl ≥1 weekend)	
No of mins/day	N	Power[a] (%)	N	Power (%)	N	Power (%)	N	Power (%)
600	5601	90.8	4980	87.4	4760	89.7	4543	88.3
540	5717	91.7	5284	89.5	5073	91.9	4924	91.1
480	5780	91.9	5448	90.4	5284	92.8	5172	92.3
420	5812	92.3	5529	91.1	5397	93.7	5304	93.3

[a]power to detect a difference of 0.07 SDs in counts per minute between two groups ($p \leq 0.05$). One SD=178 counts per minute, 0.07 SD=13 counts per minute

8.1.3 Final numbers with valid measurement

Applying the above criteria gave a final sample of 5,595 that satisfied the validity criteria – 2,662 boys and 2,933 girls (Figure 8.1). Of the 1,027 children who were excluded, 171 were excluded because of broken or malfunctioning instruments and the remainder because the monitor was worn for insufficient time.

8.1.4 Differences between participants and non-responders

Children who provided valid recordings tended to be slightly younger, shorter and lighter than children who failed to provide valid recordings but the size of these differences were small (Table 8.4). More girls than boys returned instruments with valid data (81% of girls vs. 76% of boys; $p<0.001$). Parental variables were not strongly associated with compliance. Children were more likely to comply if their mother had a higher level of education but again the differences were small.

Table 8.4 Comparison of children who had valid data with those who did not

Characteristic	Attended clinic but did not have valid data N= 1564	Attended clinic and had valid data N= 5595	P value
Continuous child variables. Mean (SD)			
Age (years)	11.81 (0.26)	11.77 (0.23)	<0.001
Height (cm)	151.1 (7.3)	150.7 (7.2)	0.097
Weight (kg)	44.9 (11.1)	43.5 (9.9)	<0.001
BMI (kg/m^2)	19.5 (3.8)	19.0 (3.3)	<0.001
Birth weight (g)	3445 (537)	3433 (523)	0.43
Categorical child variables (percentages)			
Gender (male)	53.7	49.1	<0.001
Pubertal stage (% above Tanner stage 1)	73.6 (70.3, 76.9)	78.2 (76.7, 79.7)	0.009
Parity			
0	43.8	43.4	0.66
1	32.0	32.3	
≥2	24.2	24.3	
Continuous parental variables			
Maternal height (cm)	164.3 (6.8)	164.2 (6.6)	0.50
Maternal BMI (kg/m^2)	23.0 (3.9)	22.9 (3.7)	0.34
Paternal height (cm)	176.0 (7.1)	176.4 (6.8)	0.06
Paternal BMI (kg/m^2)	25.1 (3.3)	25.1 (3.3)	0.96
Maternal age	29.0 (4.8)	29.0 (4.6)	0.78
Categorical parental variables (percentages)			
Social class			
1	27.8	29.7	0.19
2	26.2	27.2	
3	29.5	26.6	

Table 8.4 Comparison of children who had valid data with those who did not, continued

	4	16.6	16.5	
Maternal education				
	1	14.5	16.4	0.04
	2	26.6	26.7	
	3	34.4	35.8	
	4	24.5	21.1	
Paternal education				
	1	21.9	22.0	0.66
	2	27.6	28.6	
	3	21.2	21.9	
	4	29.2	27.5	

Parity was recorded at 18 weeks gestation by self-report questionnaire and is defined as the number of previous pregnancies resulting in live or still births. Socio-economic variables and parental education from self-report questionnaire at 32 weeks gestation (coded as 1= "highest"; 4= "lowest"). Maternal and partner height and BMI data were from self-report questionnaire at 12 weeks gestation.

8.1.5 Instrument reactivity, number of days of measurement and start day

The mean difference between total activity on day one and the mean of total activity on the remaining days was 17 counts per minute higher on day one (95% CI 10, 24) or about 0.1 SD. Linear regression, allowing for multiple measurements per child, indicated that day one of measurement tended to show slightly higher activity levels than subsequent days (p for trend <0.001). This remained unchanged after adjustment for gender. There was a difference between the activity levels of children with different numbers of valid days measurement and this increased slightly after adjustment for confounding factors (Table 8.5). There were also differences in total activity levels depending on which day measurement commenced (Table 8.5). There was a small difference in activity depending on whether children started on a weekday or weekend day (mean difference 17 counts per minute; 95% CI 7, 29, p<0.001). This represented about 0.1 of a SD. A total of 3474 children (62%) started on a weekday while 2121 (38%) started on a weekend day.

Table 8.5 Mean counts per minute by number of days of measurement and by start day

Number of valid days	Mean counts per minute[a]*	Frequency	Mean counts per minute[b]*	Frequency
3	630	314	618	130
4	622	527	636	269
5	619	951	626	488
6	603	1586	606	828
7	590	2217	595	1291
Total	604	5595	608	3006
$\beta = -11$ (-14, -7) $p<0.001$			$\beta = -11$ (-16, -6) $p<0.001$	

Start day	Mean counts per minute[a]*	Frequency	Mean counts per minute[b]**	Frequency
Monday	558	112	601	62
Tuesday	602	486	599	255
Wednesday	628	997	627	533
Thursday	608	924	620	479
Friday	605	955	602	526
Saturday	607	979	604	549
Sunday	582	1142	592	549
Total	604	5595	608	3006

[a]Unadjusted [b]Adjusted for age, gender, pubertal status, BMI and maternal and paternal education level and social class. *p=0.001 **p=0.007

8.1.6 Summary

- A number of variables were derived from the raw data using a custom-designed macro

- Three to seven days of at least 10 hours per day wearing the Actigraph gave a reliability coefficient of 0.7, power>90% and a sample of 5595

- Differences between participants and non-participants were observed but these tended to be small

- There was evidence of reactivity but the magnitude was small

- Differences were found in counts per minute depending on number of valid days and start day

8.2 Calibration of an accelerometer during free-living activities in children

This study was undertaken to develop a population specific equation to predict energy expenditure and to develop cut-points for moderate and vigorous physical activity. See section 6.3.2 for a description of the methods and Appendix 2 for the published paper.

8.2.1 Study participants

Of the 257 who volunteered to participate from the original sampling frame, 246 were included in the analysis. Eight were excluded due to equipment failure and three due to insufficient compliance with the protocol. Of those who were included in the analysis, 11 did not complete the hopscotch and 20 did not complete the jogging. Additionally, one sitting VO_2 that was unusually high, plus two slow walking and one walking VO_2 values that were unusually low were excluded. Data were approximately normally distributed therefore no transformations were required.

Table 8.6 summarises the characteristics of children who took part in the study.

Table 8.6 Characteristics of study sample

Characteristic	All (N=246)	Boys (N=110)	Girls (N=136)
Age (years)[a]	12.4 (0.2)	12.4 (0.2)	12.4 (0.2)
BMI (kg/m^2)[b]	18.7 (17.1, 21.2)	18.6 (17.1, 21.0)	18.9 (17.3, 21.3)
Height (cm)[a]	150.3 (6.8)	149.9 (7.3)	150.6 (6.3)
Weight (kg)[b]	41.6 (35.4, 47.8)	41.2 (34.4, 47.0)	42.3 (36.4, 48.3)
Social class (% non-manual)	56	56.3	55.8

[a] Mean (SD)
[b] Median (IQR)

Table 8.7 shows the numbers of children who completed each activity along with the mean (SD) values for walking and jogging speeds, Actigraph counts per minute, energy expenditure (kJ·kg·min^{-1}) and VO_2 (mL·kg^{-1}·min^{-1}). Activities are shown in order of increasing intensity. Accelerometer counts for lying and sitting are not shown, as these were zero for 88.2% of the lying values and 72.7% of the sitting values. These two activities were excluded from all further analysis.

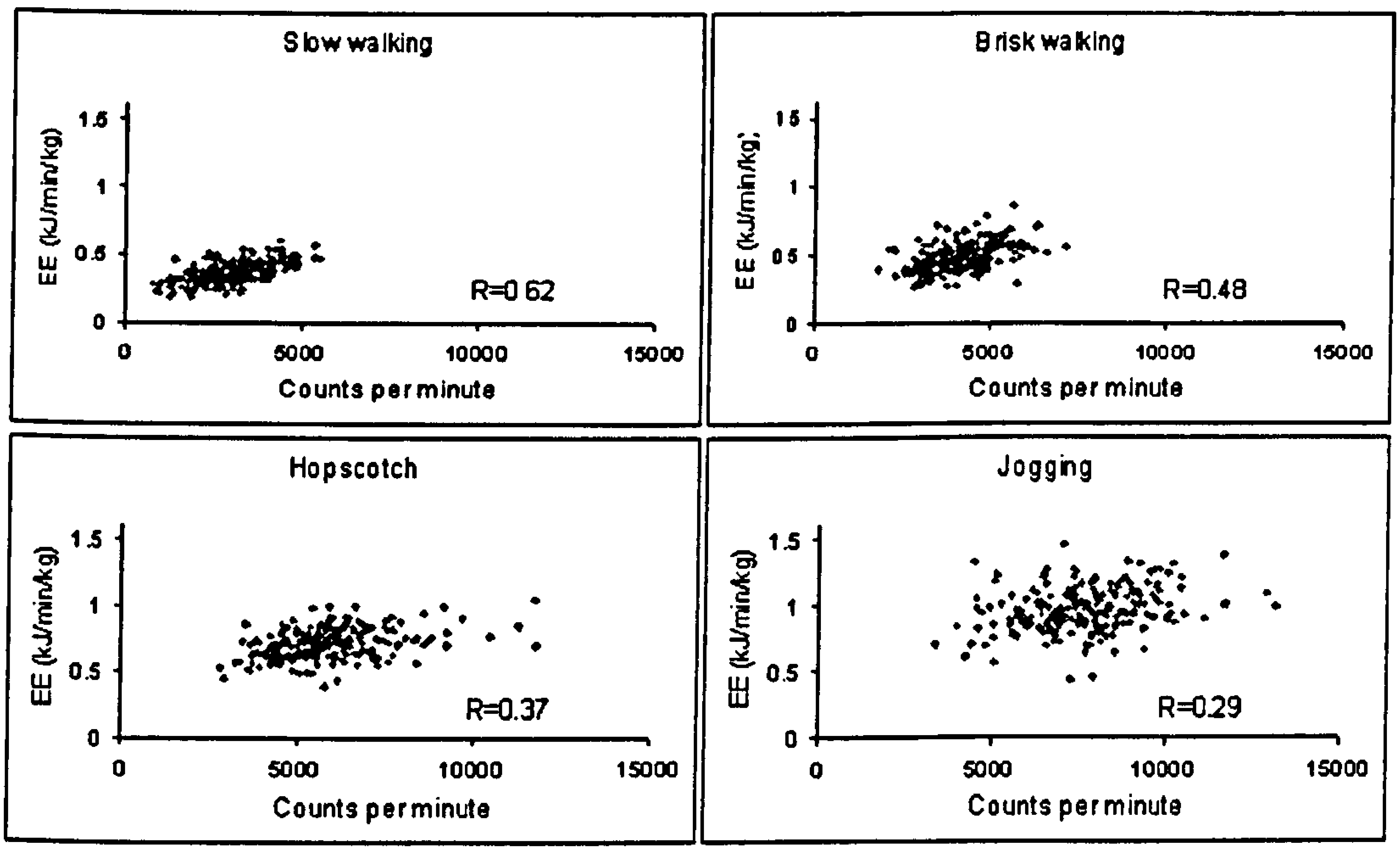
Table 8.7 Mean (SD) accelerometer counts per minute, energy expenditure and VO_2 for each activity

Activity	Lying	Sitting	Slow walking	Brisk walking	Hopscotch	Jogging
N	246	245	244	246	235	226
Speed (kph)	–	–	4.4 (0.7)	5.8 (0.8)	–	9.2 (1.5)
Counts per minute	–	–	2954 (984)	4175 (935)	5863 (1501)	7667 (1598)
Energy expenditure (kJ·kg·min^{-1})	0.13 (0.03)	0.12 (0.03)	0.37 (0.08)	0.48 (0.10)	0.71 (0.12)	0.96 (0.17)
VO_2 (mL·kg^{-1}·min^{-1})	6.1 (1.4)	6.0 (1.3)	17.7 (3.6)	22.8 (4.5)	34.2 (5.2)	44.9 (7.2)
VO_2 (L·min^{-1})	0.28 (0.07)	0.28 (0.07)	0.83 (0.23)	1.06 (0.27)	1.57 (0.31)	2.06 (0.42)

8.2.2 Derivation of prediction equation

Figure 8.4 shows the relationship between counts per minute and energy expenditure for each activity for the whole sample. Unadjusted Pearson's correlation coefficients are also shown on each graph. Correlations were highest for the locomotor activities. The unadjusted Pearson's correlation for all activities combined was 0.82; $p<0.001$.

Figure 8.4 Relationship between counts per minute and energy expenditure for each activity



All p<0.001. EE = energy expenditure

The developmental group comprised 73 boys and 90 girls. The equation derived to predict energy expenditure from accelerometer counts is:

> Energy expenditure ($kJ \cdot kg \cdot min^{-1}$)= - 0.933 + 0.000098 counts per minute + 0.091 age (years) - 0.0422 gender (male =0, female = 1). (SE for counts per minute 2.56×10^{-6}, $R^2 = 67.3\%$).

Backwards elimination confirmed that both potential confounders (age and gender) were required in the equation. The R^2 value of 67.3% suggests that a considerable amount of the variability in energy expenditure is explained by for counts per minute. There was only weak evidence [130] of a gender*counts interaction (p=0.04), we therefore followed Kirkwood and Sterne's (p. 466) recommendation that a single model was sufficient to describe the data [169].

The validation group comprised 37 boys and 46 girls. To validate the equation, limits of agreement were calculated (limits of agreement = mean difference +/- the standard deviation of the difference). In the validation group, the mean difference between actual and predicted energy expenditure was -0.01 $kJ \cdot kg \cdot min^{-1}$ and the limits of agreement were -0.28, 0.25. In the developmental group, the mean difference was 0.0 kJ·kg·min^{-1} and the limits of agreement were -0.29, 0.30.

The fit of the prediction equation was checked (normal probability plot of residuals and plot of the residuals against the predicted values; data not shown) and deemed to be adequate. Removing confounding variables one at a time from the equation resulted in the following attenuations of R^2 from 67.3%: age 66.7%; gender 66.2%.

8.2.3 Derivation of activity intensity thresholds

Physical activity intensity cut-points were derived by refitting the prediction equation with VO_2 rather than energy expenditure as the outcome, based on the developmental group (METs are defined as multiples of resting VO_2). The mean resting VO_2 value in the developmental group was 5.7 mL·kg^{-1}·min^{-1} (the minimum of lying or sitting VO_2), which was established as one MET. Table 8.8 shows the lower thresholds for moderate (three and four METs) and vigorous activity (six METs), based on unadjusted and adjusted models. Values are also given for boys and girls separately, adjusting for age. For the cut-points, the adjusted figures were a lower threshold of 3581 counts per minute for moderate activity and 6130 counts per minute for vigorous activity.

Table 8.8 Threshold values of counts per minute for moderate and vigorous activity

METs	Unadjusted - all	Adjusted[a] - all	Adjusted[b] - boys	Adjusted[b] - girls
N	163	163	73	90
3	2323	2306	2184	2389
4	3589	3581	3382	3731
6	6121	6130	5777	6415

[a]Adjusted for age and gender
[b]Adjusted for age only

For the threshold for moderate activity (four METs), sensitivity was 95.5% and specificity was 60.7%, based on the validation group. Using three METs as the threshold for moderate, sensitivity was 98.2% and specificity was 40.5%. For vigorous activity (six METs) in the same group of children, sensitivity and specificity were 74.1% and 94.7% respectively.

8.2.5 Summary

- The R^2 value of 67.3% suggests that the Actigraph was able to predict energy expenditure and O_2 uptake reasonably well
- Cut-points for moderate and vigorous activity were derived

8.3 Intra-individual variation of objectively measured physical activity in children

This was a repeat measures study where a sub sample of children who had successfully worn the Actigraph at the 11 year clinic were asked if they would be willing to take part in an unspecified further study. This study was undertaken to characterise intra-individual variation in physical activity and to describe any seasonality in physical activity. See Appendix 3 for paper and Section 6.2 for a description of the methods.

8.3.1 Study participants

Of the 548 children who were contacted, 349 (64%) agreed to participate in the study. Of those who agreed to participate, 315 (90%) had valid data for Season 1, 300 (86%) for Season 2, 282 (81%) for Season 3 and 273 (78%) for Season 4. Two hundred and forty-four (70%) children had valid data for all four seasons. Valid data was defined as having at least three days measurement of at least 10 hours per day although the mean (SD) number of hours the monitor was worn per day was 13.1 (0.8). The median (IQR) length of time between each measurement and the geometric mean (IQR) counts per minute at each measurement is shown in Figure 8.5. The mean valid number of days of measurement for Seasons 1-4 were 6.1, 5.8, 5.6 and 5.6, respectively.

Figure 8.5 Timeline of measurement occasions with geometric mean (IQR) for counts per minute and median (IQR) number of days between measurements

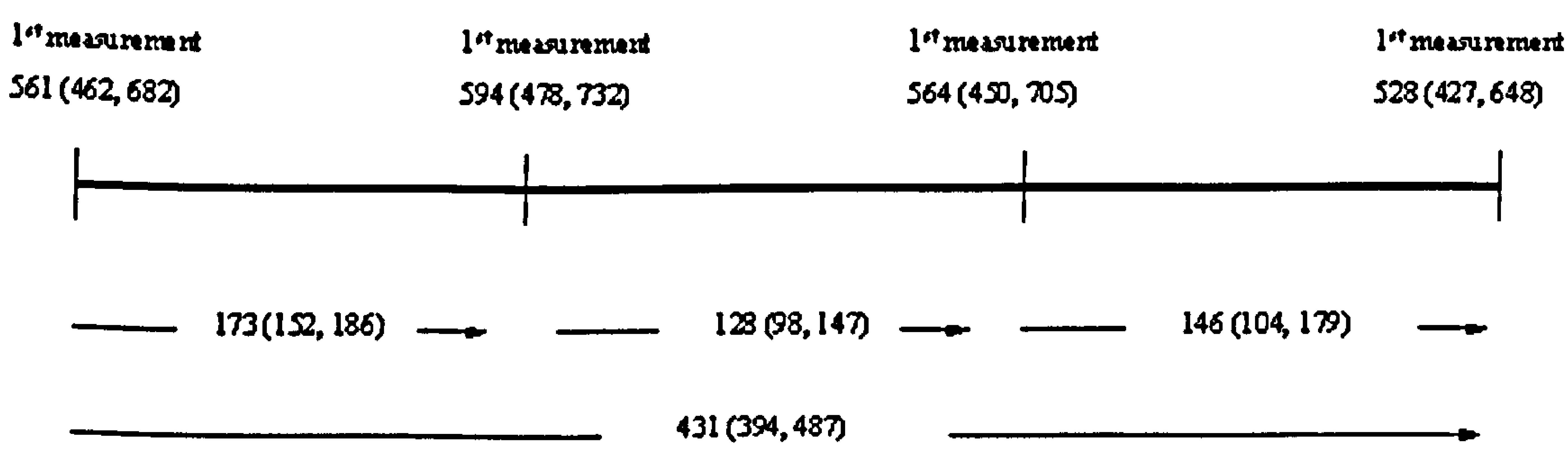


Table 8.9 shows the characteristics of participants compared with all children who attended the 11-year clinic. Children who participated in this study tended to be younger, shorter, lighter and from higher socio-economic backgrounds than those who attended the 11-year clinic although the differences were small and most p values for the differences were >0.05.

Table 8.9 Comparison of characteristics between study sample and ALSPAC 11 year clinic

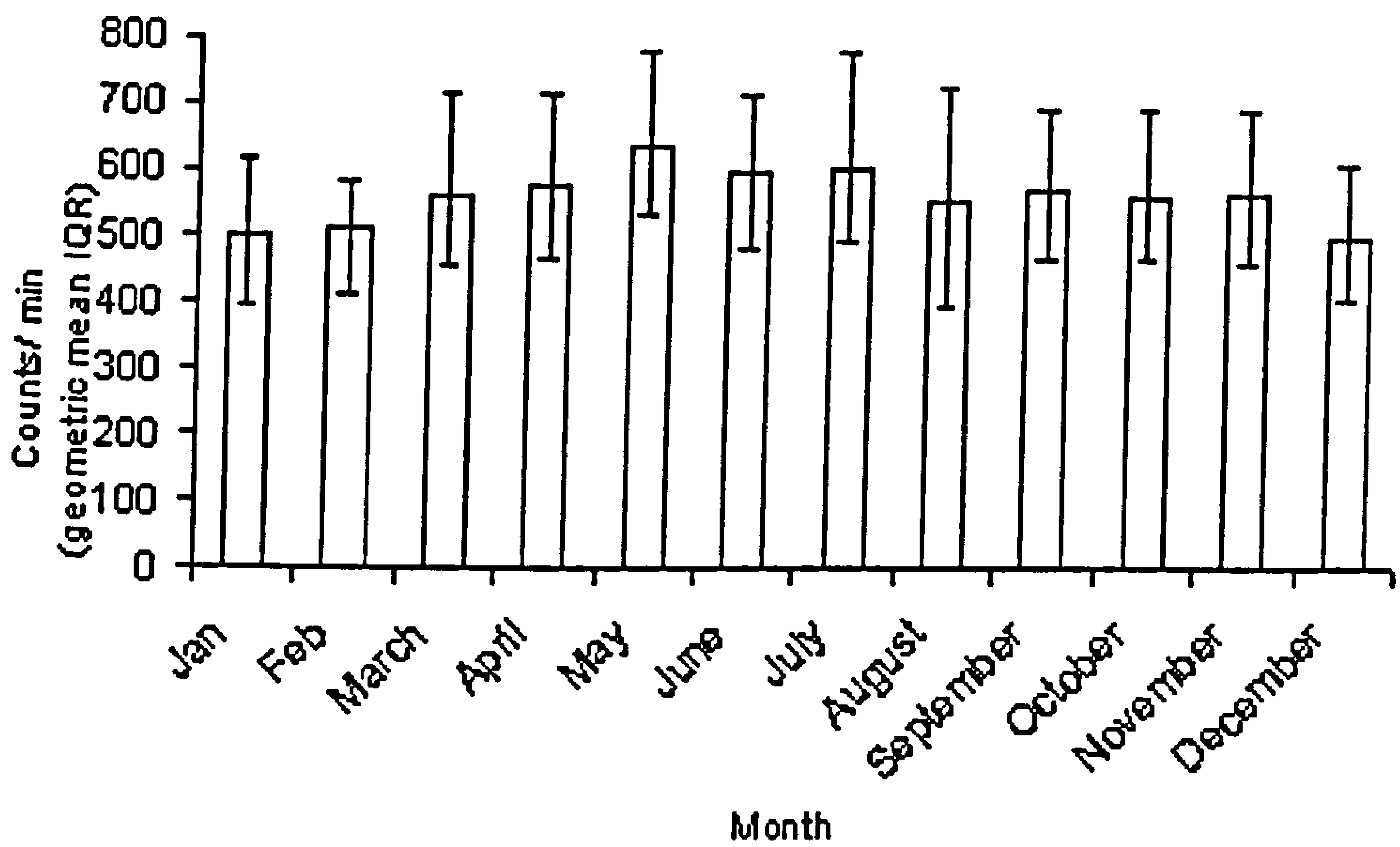
Characteristic	All		Boys		Girls	
	Current Study (N=315)	11 year clinic (N=6844)	Current Study (N=148)	11 year clinic (N=3370)	Current Study (N=167)	11 year clinic (N=3474)
Age (years)[a]	11.65‡ (0.19)	11.79 (0.24)	11.64§ (0.18)	11.78 (0.24)	11.67¶ (0.21)	11.79 (0.24)
BMI (kg/m^2)[b]	18.2 (16.4, 20.7)	18.3 (16.6, 20.9)	17.7 (16.4, 20.2)	18.0 (16.5, 20.6)	18.5 (16.3, 21.0)	18.6 (16.8, 21.3)
Height (cm)[a]	150.0* (7.4)	150.8 (7.3)	148.8† (6.7)	150.1 (7.2)	151.1 (7.8)	151.5 (7.3)
Weight (kg)[b]	41.0 (35.8, 48.6)	41.8 (36.4, 49.4)	40.2 (35.0, 46.0)	40.8 (35.8, 47.8)	41.6 (36.0, 50.0)	43.0 (37.0, 50.6)
Socioeconomic status (% non-manual)	59.0	56.0	59.6	56.6	58.4	55.4

[a] Mean (SD) [b] Median (IQR)
‡p<0.001 for difference between all in this study and all in 11-year clinic
§p<0.001 for difference between boys in this study and boys in 11-year clinic
¶p<0.001 for difference between girls in this study and girls in 11-year clinic
*p<0.05 for difference between all in this study and all in 11-year clinic
†p<0.05 for difference between boys in this study and boys in 11-year clinic

8.3.2 Seasonality of physical activity

Figure 8.6 shows the geometric means for each month of the year with children tending towards lower physical activity in the winter months.

Figure 8.6 Geometric means (IQR) by month of the year



Means may be based on multiple observations per child

The forwards stepwise procedure suggested that gender, age and BMI should be included as potential confounders in the model for seasonality of physical activity. Comparing sine and cosine functions of month of measurement demonstrated that one sine and one cosine function were required for most of the summary measures, thus allowing one peak and one trough within the year. Minutes of MVPA required two sine and two cosine functions to account for two peaks and two troughs. Figures 8.7 and 8.8 show the predicted means for counts per minute and minutes of MVPA fitted with the sine and cosine functions. The differences between the lowest and highest months (January and June, respectively) is about 100 counts per minute and about 5 minutes for MVPA (January and April lowest and highest months, respectively).

Figure 8.7 Predicted geometric means for counts per minute from model with one sine and cosine function for month

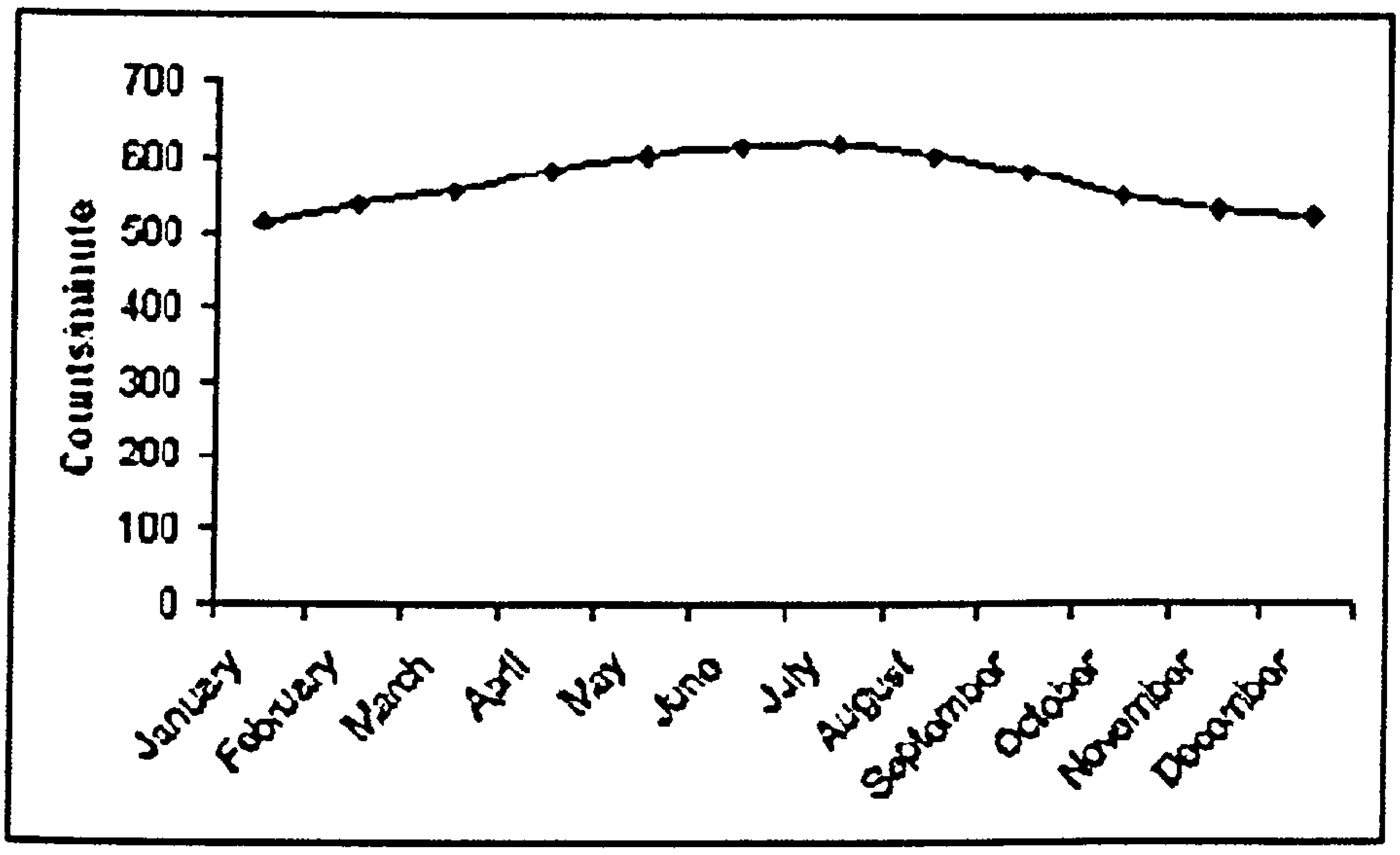


Figure 8.8 Predicted geometric means for MVPA from model with two sine and cosine functions for month

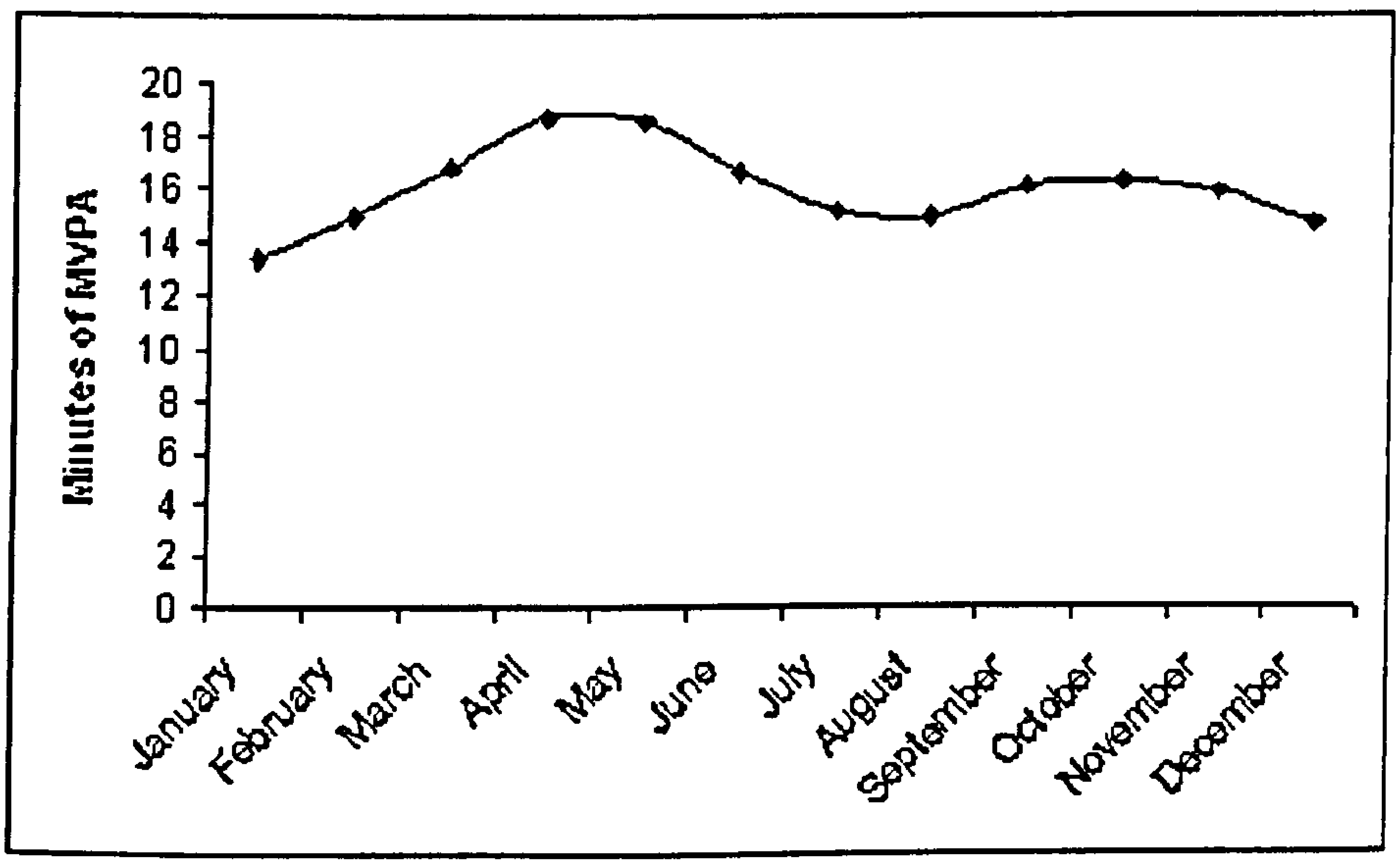


Table 8.10 summarises the unadjusted and adjusted physical activity summary measures, intra-individual standard deviations, CV and ICC. Adjustment for confounding variables had little effect on these estimates.

Table 8.10 Intraclass correlation co-efficients for physical activity summary measures

	Unadjusted	Partially adjusted[a]	Fully adjusted[b]
Geometric mean (counts per minute)	563	563	567
Intra-individual SD	0.20	0.20	0.19
CV*	22.46%	22.28%	21.30%
ICC**	0.54	0.49	0.53
Geometric mean weekday (counts per minute)	567	567	571
Intra-individual SD	0.21	0.21	0.20
CV*	23.10%	22.97%	21.87%
ICC**	0.54	0.48	0.51
Geometric mean weekend (counts per minute)	518	515	521
Intra-individual SD	0.35	0.35	0.34
CV*	41.94%	41.57%	40.00%
ICC**	0.38	0.39	0.39
Geometric mean minutes MVPA[c]	16.1	16.1	15.9
Intra-individual SD	0.53	0.53	0.53
CV*	70.50%	70.29%	69.27%
ICC**	0.51	0.46	0.45
Geometric mean minutes vigorous activity	2.1	2.1	2.2
Intra-individual SD	0.89	0.89	0.88
CV*	143.50%	143.63%	140.29%
ICC**	0.40	0.36	0.37
Geometric mean minutes sedentary	441	441	440
Intra-individual SD	0.10	0.10	0.10
CV*	10.90%	10.64%	10.22%
ICC**	0.57	0.58	0.59
Geometric mean ≥30 minute blocks sedentary	0.8	0.8	0.8
Intra-individual SD	0.63	0.61	0.61
CV*	87.64%	85.40%	83.59%
ICC**	0.39	0.39	0.39

*CV = coefficient of variation = SD as % of mean
**ICC = intraclass correlation coefficient = inter-individual variance / total variance
[a]adjusted for gender, age, BMI; [b]adjusted for gender, age, BMI and month [c]adjusted for month with two sine and two cosine functions

Excluding any measurement occasions where children reported any swimming or cycling (restricting the analysis to 291 children), the ICC and CV for counts per minute, adjusted for gender, age, BMI and month were 0.53 and 20.48%, respectively. Excluding weekdays when children were not at school during the measurement period e.g., during school holidays, the ICC and CV, adjusted for gender, age, BMI and month were 0.53 and 20.56%, respectively. Finally, restricting to those children with data for all four seasons (244 children), the ICC and CV, adjusted for gender, age, BMI and month were 0.53 and 21.01%, respectively. The ICC and CV were similar whether unadjusted or adjusted for gender, age and BMI. Applying the above restrictions had little effect on the ICCs for the whole sample, suggesting that the different pattern of non-school days or that the lack of physical activity measurement implied by time spent cycling or swimming added little to the overall variability.

A comparison of the ICC for different numbers of days of measurement on each measurement occasion for counts per minute and minutes of MVPA showed increasing ICCs and decreasing variability as number of days included in the model increased (see Table 8.11). The ICCs for 5 and 6 or 7 days of measurement were similar to the final model where 3-7 days were used.

Table 8.11 Intraclass correlation co-efficients for selected physical activity summary measures for different numbers of days of measurement per occasion

	Three days	Four days	Five days	Six or seven days
N[a]	244	215	161	87
Geometric mean[b] (counts per minute)	556	554	557	566
Intra-individual SD	0.23	0.21	0.19	0.18
CV*	25.75%	23.48%	21.26%	19.60%
ICC**	0.45	0.48	0.52	0.56
Geometric mean minutes MVPA[c]	14.8	15.2	15.8	16.7
Intra-individual SD	0.64	0.59	0.54	0.50
CV*	89.29%	80.31%	71.95	64.47%
ICC**	0.38	0.40	0.44	0.46

*CV = coefficient of variation = SD as % of mean **ICC = intraclass correlation coefficient = inter-individual variance / total variance [a]Numbers restricted to those with data for all 4 measurement occasions [b]Adjusted for gender, age, BMI and month; [c]Adjusted for gender, age, BMI and for month with two sine and two cosine functions

8.3.3 Summary

- Children tended to be more active in the spring and summer than in the autumn and winter

- Intra-class correlation coefficients (ICC) were 0.53 for counts per minute and 0.45 for minutes of MVPA

- ICCs for counts per minute increased with increasing number of days of measurement

8.4 Objective measurement of levels and patterns of physical activity

This section reports the results from the Descriptives paper (see Appendix 4 for paper and Section 6.2 for a description of the methods). This study was undertaken to describe the levels and patterns of physical activity in ALSPAC.

8.4.1 Study participants

The sample used in this study is identical to the one used in the Methods study (see Section 8.1) and the description of the sample is repeated here. A total of 7,159 children attended the 11-year clinic and 6,622 (92.5%) agreed to wear an Actigraph. Of the children who agreed to participate, 2,662 boys and 2,933 girls returned Actigraphs that satisfied the validity criteria. Children who provided valid recordings differed from children who failed to provide valid recordings in terms of age, weight, BMI, sex and pubertal status but the size of the differences were small. More girls than boys returned instruments with valid data (81% of girls vs. 76% of boys; $p<0.001$). Parental variables were not strongly associated with compliance. Children were more likely to comply if their mother had a higher level of education but again the differences were small. Full details of the participants can be seen in section 8.1.

8.4.2 Description of physical activity levels

Table 8.12 shows the main descriptive and physical activity data for boys and girls. Overall, boys had higher activity levels than girls (115 counts per minute difference). Boys also participated in more MVPA. Both boys and girls spent the majority of their active time in light intensity activity (200-3599 counts per minute). Few children of either gender (5.1% of boys and 0.5% of girls) met physical activity recommendations for children of achieving at least 60 minutes of MVPA per day.

Table 8.12 Physical characteristics and main physical activity variables. Median and inter-quartile range (IQR) unless otherwise stated

	ALL		BOYS		GIRLS		P
N		N=5595		N=2662		N=2933	
Age (y)	11.8	11.6, 11.9	11.7	11.6, 11.9	11.8	11.6, 11.9	0.218
Height (cm)	150.5	145.7, 155.4	149.6	144.9, 154.6	151.3	146.3, 156.2	<0.001
Weight (kg)	41.6	36.2, 49.0	40.4	35.6, 47.2	42.8	37.0, 50.4	<0.001
BMI (kg/m^2)	18.7	16.6, 20.7	18.5	16.4, 20.4	19.0	16.7, 21.1	<0.001
Overall activity (counts per minute)	580	474, 710	644	528, 772	529	444, 638	<0.001
Physical activity weekdays (counts per minute)	579	475, 715	644	533, 784	529	445, 635	<0.001
Physical activity weekend (counts per minute)	548	413, 723	599	443, 791	510	390, 656	<0.001
Sedentary activity* (min/d)	430	384, 474	420	373, 464	440	394, 482	<0.001
Light activity* (min/d)	322	284, 362	330	291, 371	315	278, 353	<0.001
Moderate activity* (min/d)	17	10, 27	22	14, 33	13	8, 21	<0.001
Vigorous activity* (min/d)	2	1, 4	3	1, 5	2	1, 3	<0.001
MVPA (min/d)	20	12, 31	25	16, 38	16	10, 25	<0.001
Proportion of children meeting recommended activity level** (%,95%CI)	2.6	2.2, 3.0	5.1	4.2, 5.9	0.5	0.2, 0.7	<0.001

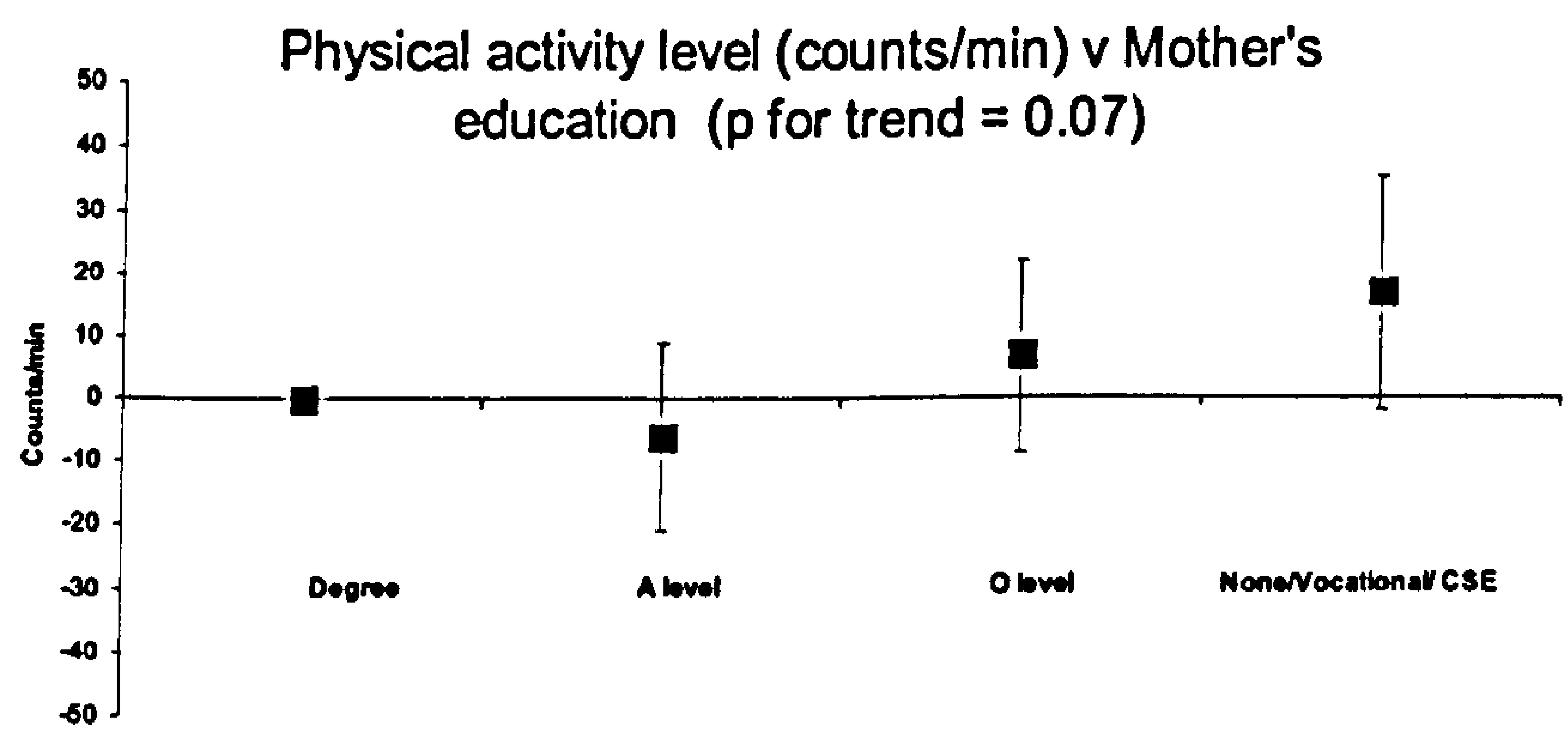
* Cut-points used: Sedentary = <200; Light = 200-3599; Moderate = 3600-6199; Vigorous = 6200+
** Recommended activity level = >60 minutes of MVPA activity daily.
P values relate to gender differences
Small discrepancies in totals are due to rounding errors

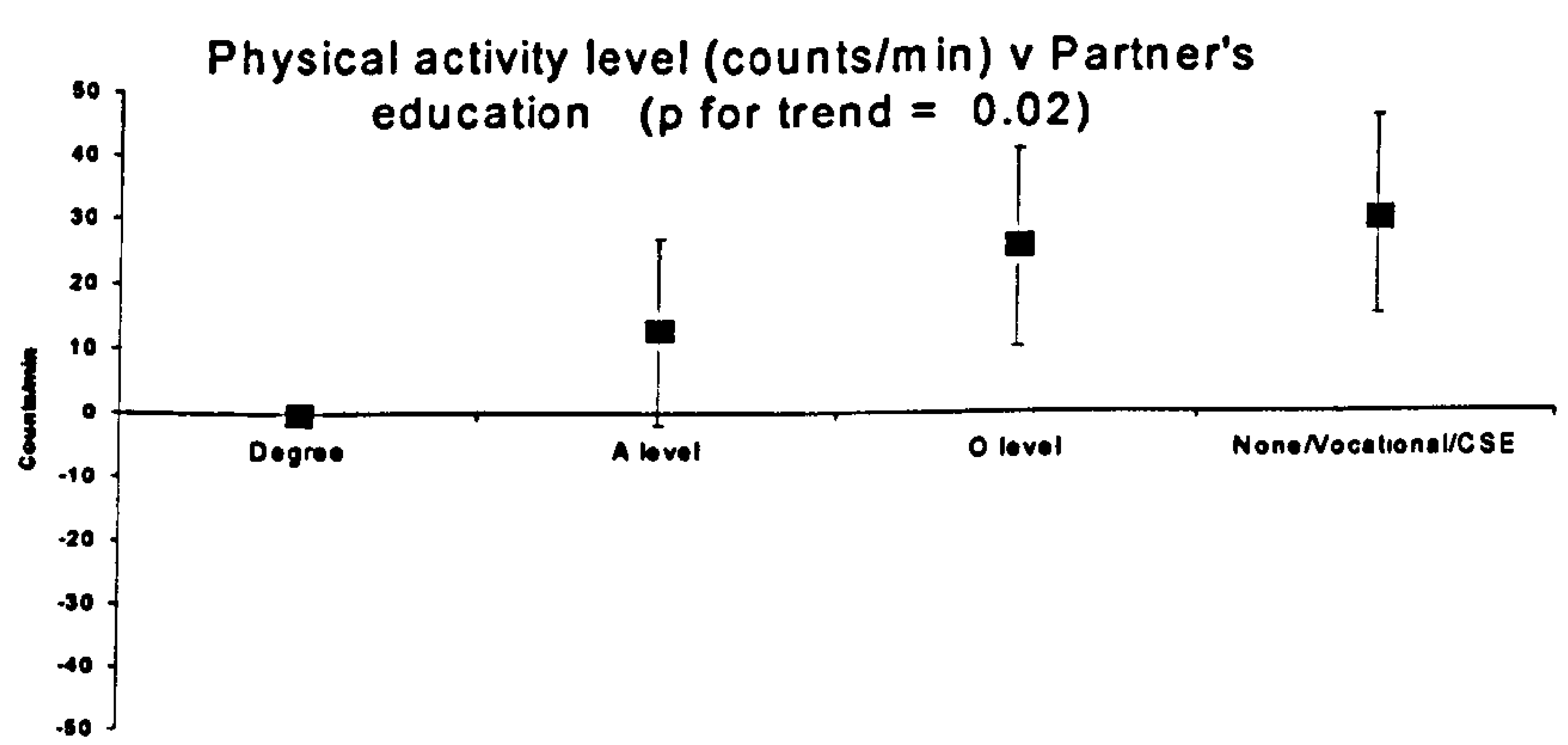
8.4.3 Social patterning of physical activity

Social class was inversely associated with total physical activity (p for trend < 0.001), but the association was attenuated after adjustment for age, gender, maternal age and mother and partner's education. Social class was not associated with MVPA in either unadjusted or adjusted models. Both the mother's and partner's education level were inversely associated with activity level (p for trend <0.001; both mother and partner). The association attenuated for mother's education (p for trend = 0.07) and somewhat attenuated for partner's education (p for trend =0.02), after adjustment for age, gender, season, maternal age and social class.

Figure 8.9 shows the association between mother and partner's education level and their child's activity level.

Figure 8.9 Social patterning of physical activity

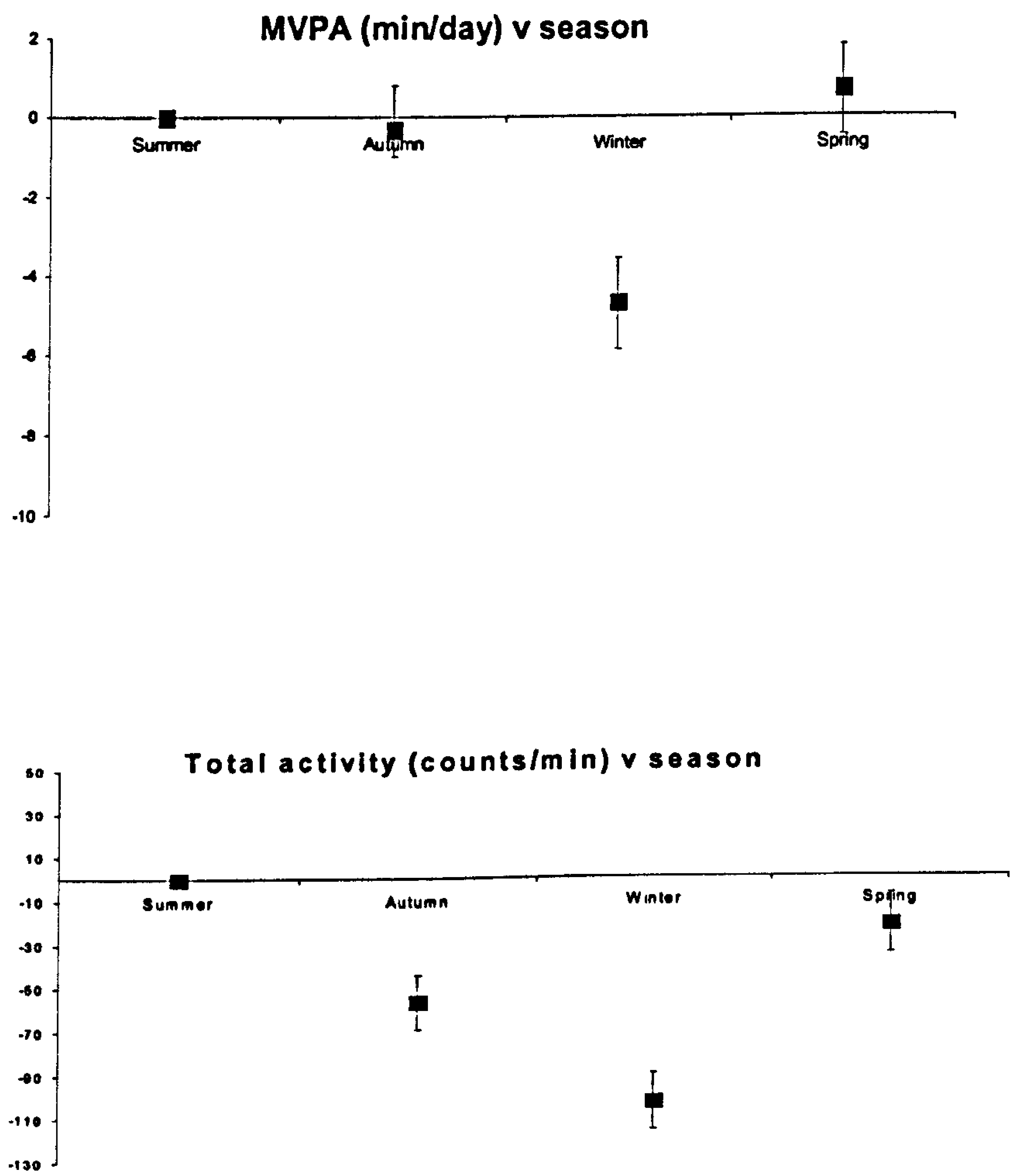




8.4.4 Seasonality of physical activity

Figure 8.10 shows the influence of season on physical activity level (counts per minute) and MVPA, adjusted for age and gender. Activity levels were lowest in winter.

Figure 8.10 Seasonality of physical activity

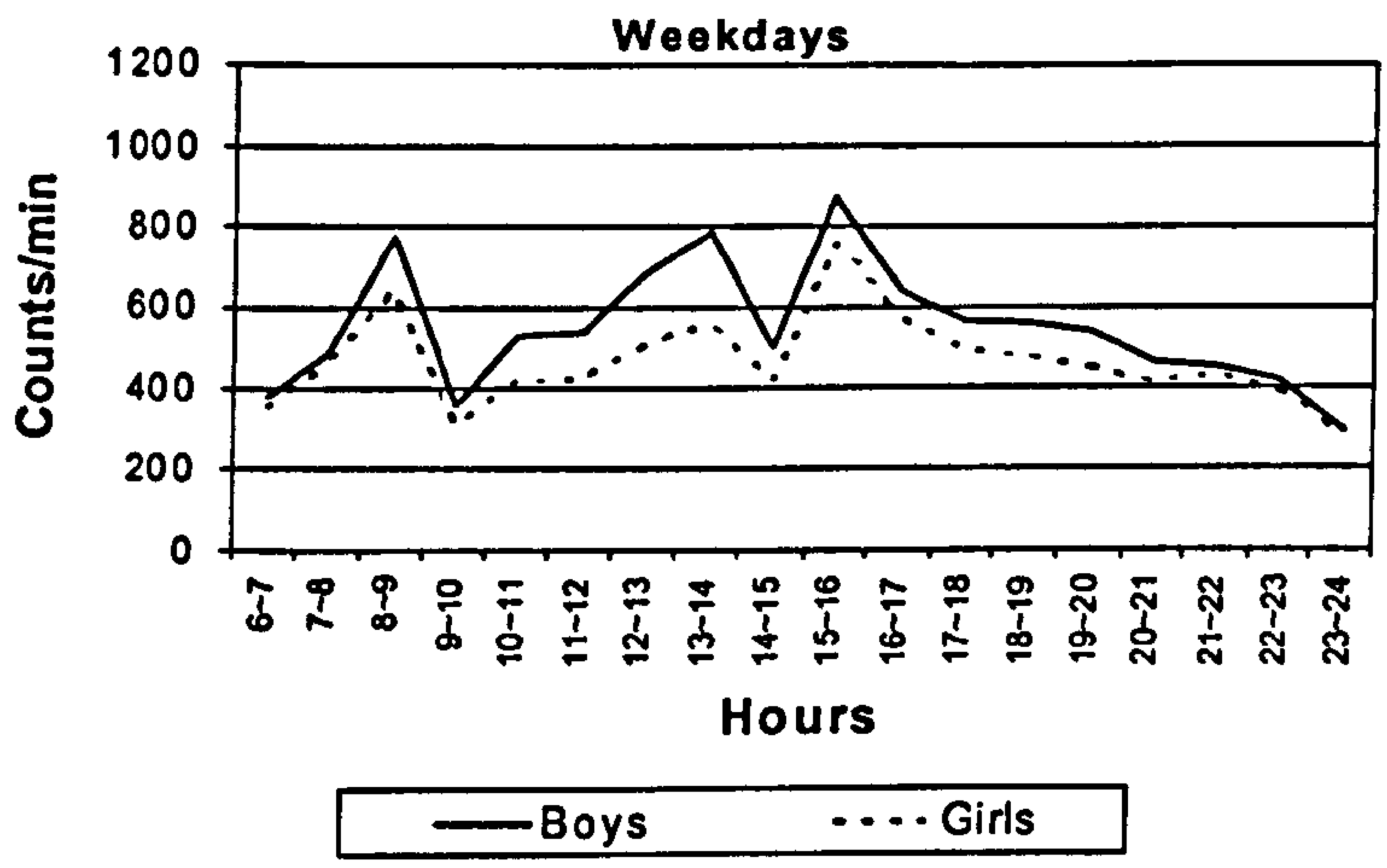


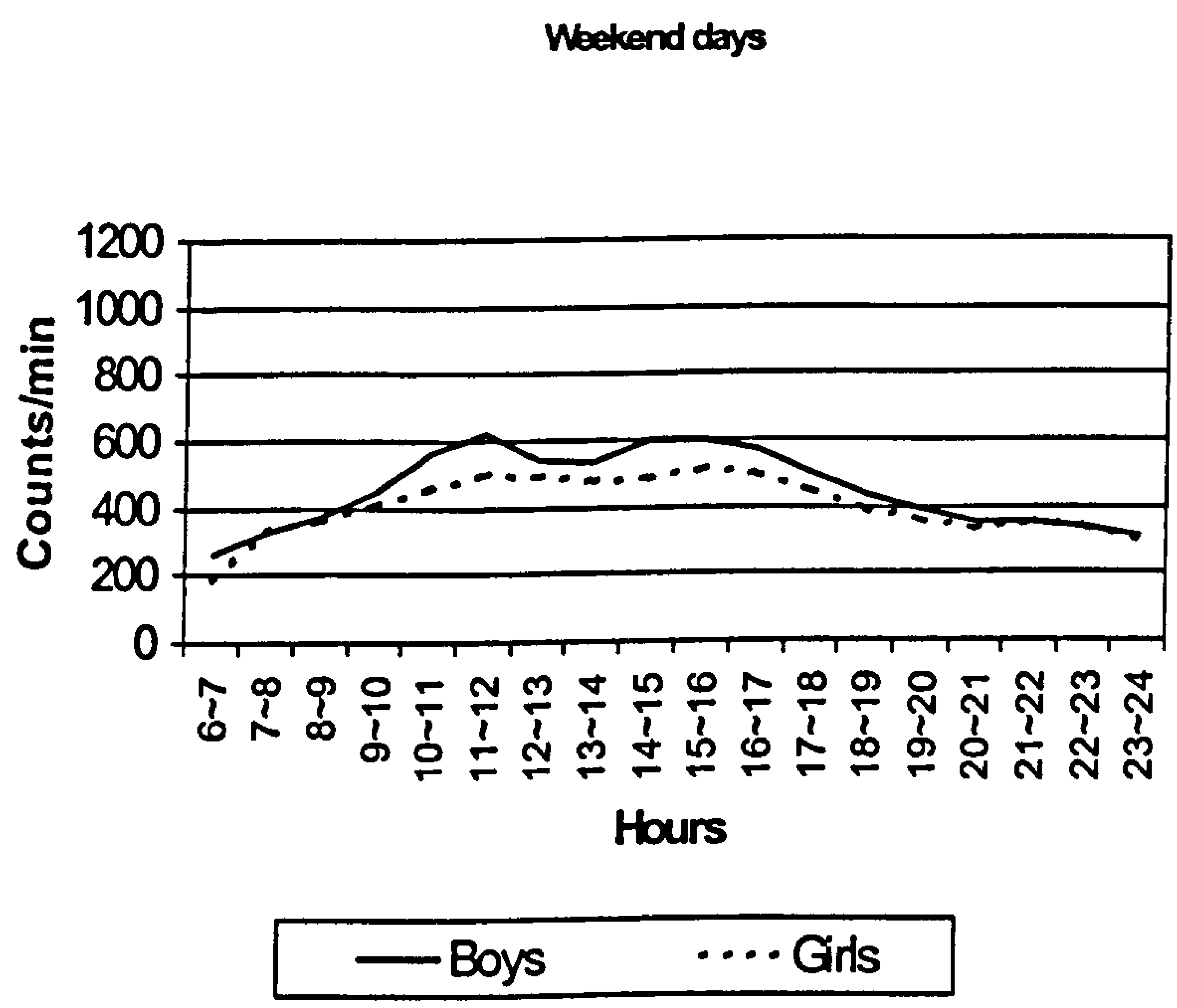
Seasons. Summer (baseline): 1st June – 31st August; Autumn: 1st September – 30th November; Winter: 1st December – 28th February; Spring: 1st March – 31st May
P <0.001

8.4.5 Daily patterns of physical activity

Figure 8.11 shows the daily physical activity patterns of boys and girls for weekdays and weekend days. Differences in activity patterns can be observed between weekdays and weekend days in both boys and girls. Weekdays were more varied, with peaks and troughs, which is likely to be due to the patterns in s typical school day. Weekend was less varied which may be due to a less rigid pattern such as is observed on schooldays. The activity patterns of boys and girls are similar.

Figure 8.11 Daily patterns of physical activity for weekdays and weekend days among boys and girls





Figures 8.12 and 8.13 show the daily physical activity patterns of the most and least active (highest/lowest quintiles) boys and girls for weekdays and weekend days. Again, the patterns of the two groups are similar, differing only in the amount of activity performed. During weekdays, the period between the end of school (mid-afternoon) and bedtime seems to be the period of the day when the largest differences in activity occur. During weekend days, patterns are again very similar with larger differences in activity levels being seen in the boys.

Figure 8.12 Daily patterns of weekday physical activity among the most active and least active boys and girls

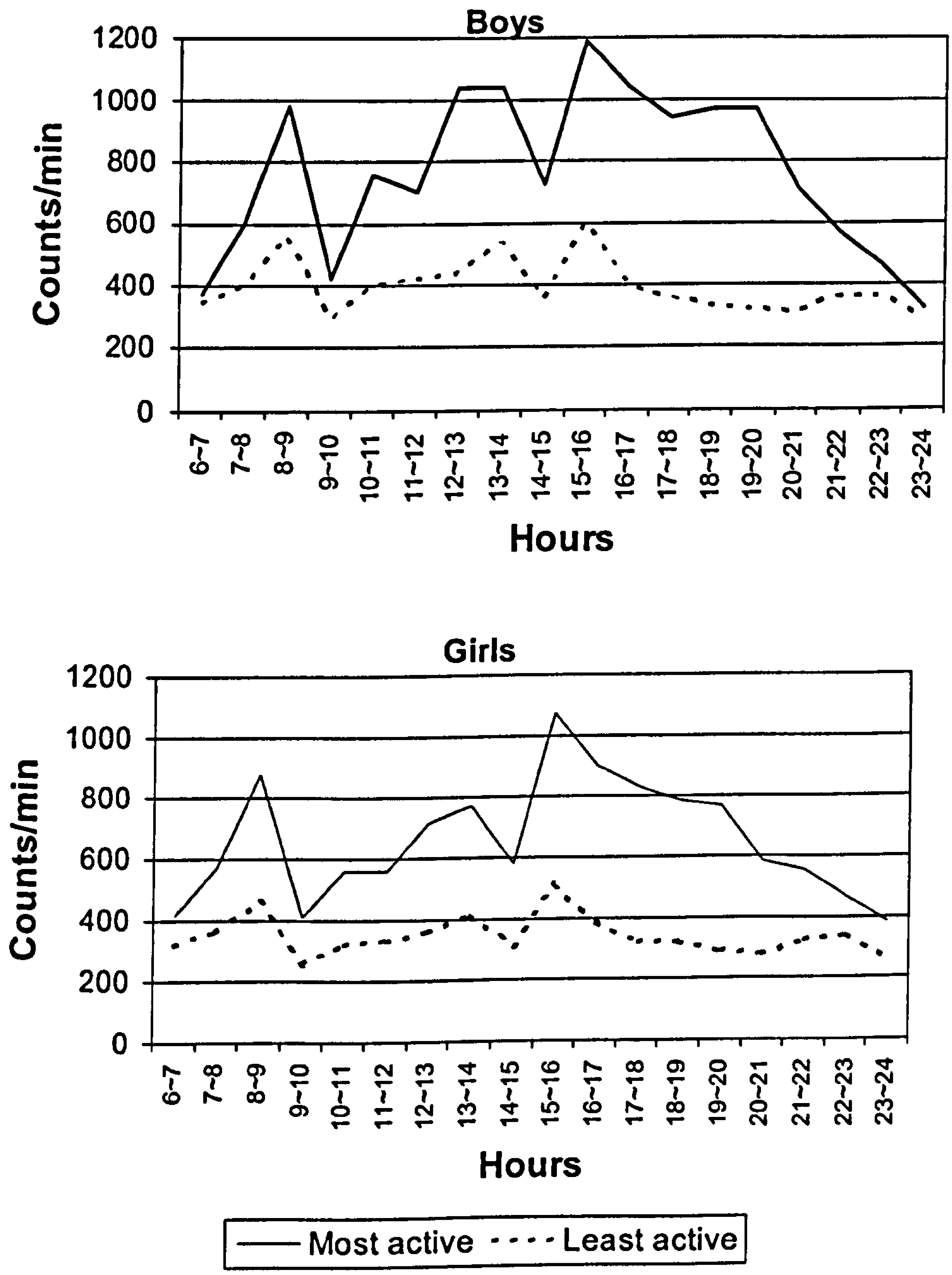
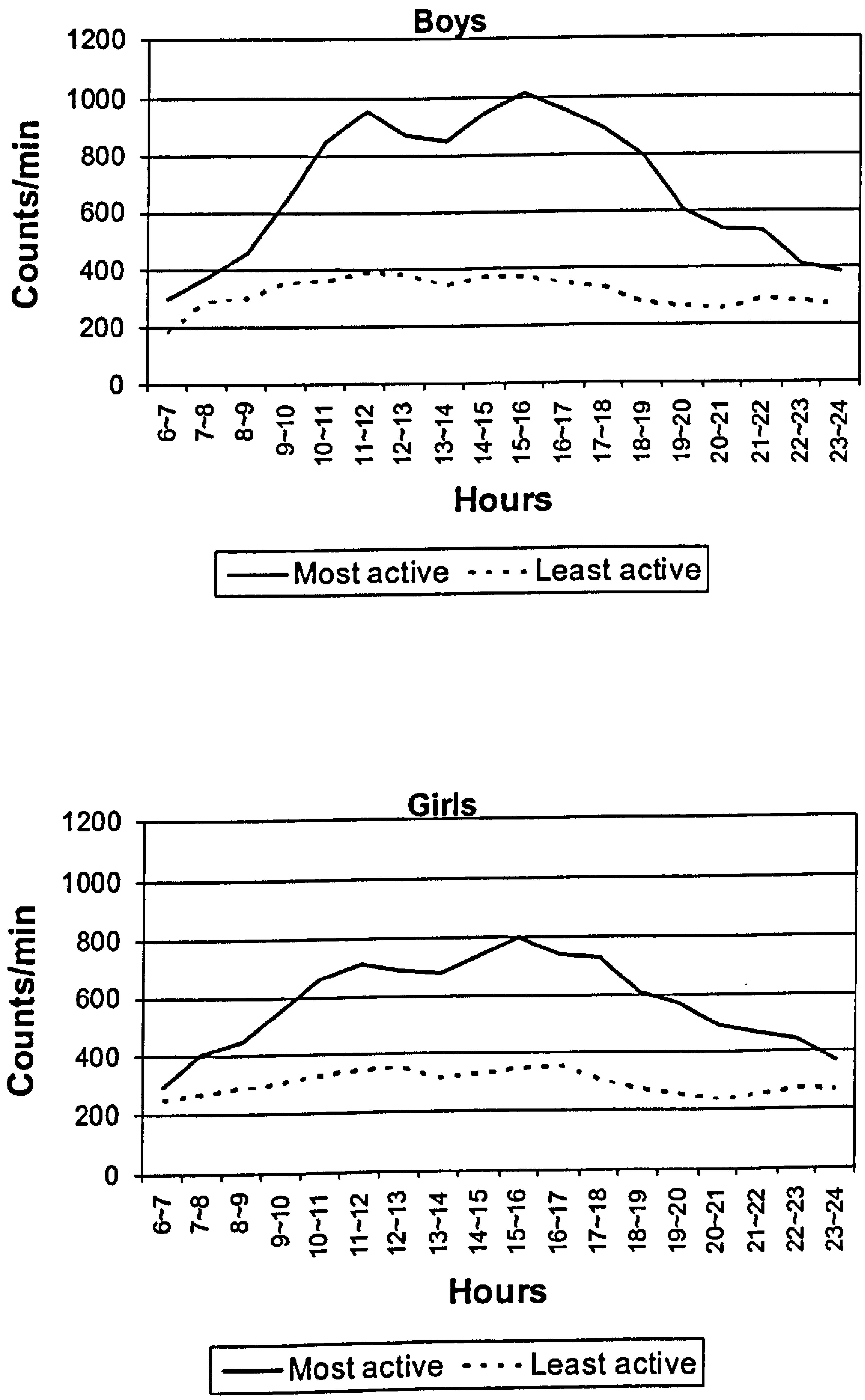


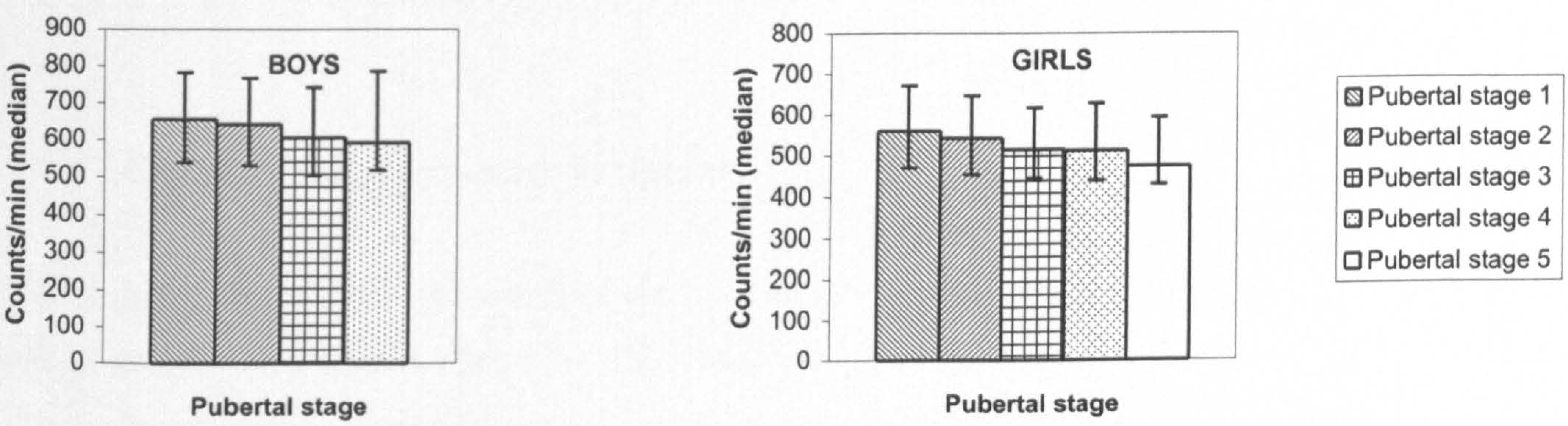
Figure 8.13 Daily patterns of weekend physical activity among the most active and least active boys and girls



8.4.6 Physical activity and pubertal stage

Differences in activity levels by pubertal stage are shown in Figure 8.14. For girls, Tanner stages one to five were used. For boys, analyses were restricted to Tanner stages one to four only, as it was unlikely that any boys at this age (11-12 years) would be in Tanner stage five. All these analyses were restricted to those children who had returned their puberty questionnaire within 16 weeks of obesity measurement. There was much stronger evidence for a trend in girls than there was in boys though the differences in physical activity between Tanner stages were modest Boys' pubertal stage 1 vs pubertal stage 4 was 657 vs 593 counts per minute. Girls' pubertal stage 1 vs pubertal stage 5 was 538 vs 473 counts per minute.

Figure 8.14 Physical activity by pubertal stage in boys and girls



p for linear trend =0.119

p for linear trend <0.001

8.4.7 Summary

- Boys were more active than girls
- Both genders spent the majority of their time in light activity
- Few children of either gender met current guidelines of at least 60 minutes of MVPA per day
- Physical activity tended to be inversely socially patterned
- Children were less active during the winter months
- Daily patterns of activity showed peaks of troughs of activity during the week with a flatter pattern at the weekend
- Children of both genders tended to be less active if they were more advanced in pubertal stage, though this was more pronounced in girls

8.5 Early life determinants of physical activity in 11 to 12 year old: cohort study

This study was undertaken in order to identify factors early in children's lives (from foetal to age 5) were associated with later physical activity at ages 11 to 12. The paper published from this work is in Appendix 5.

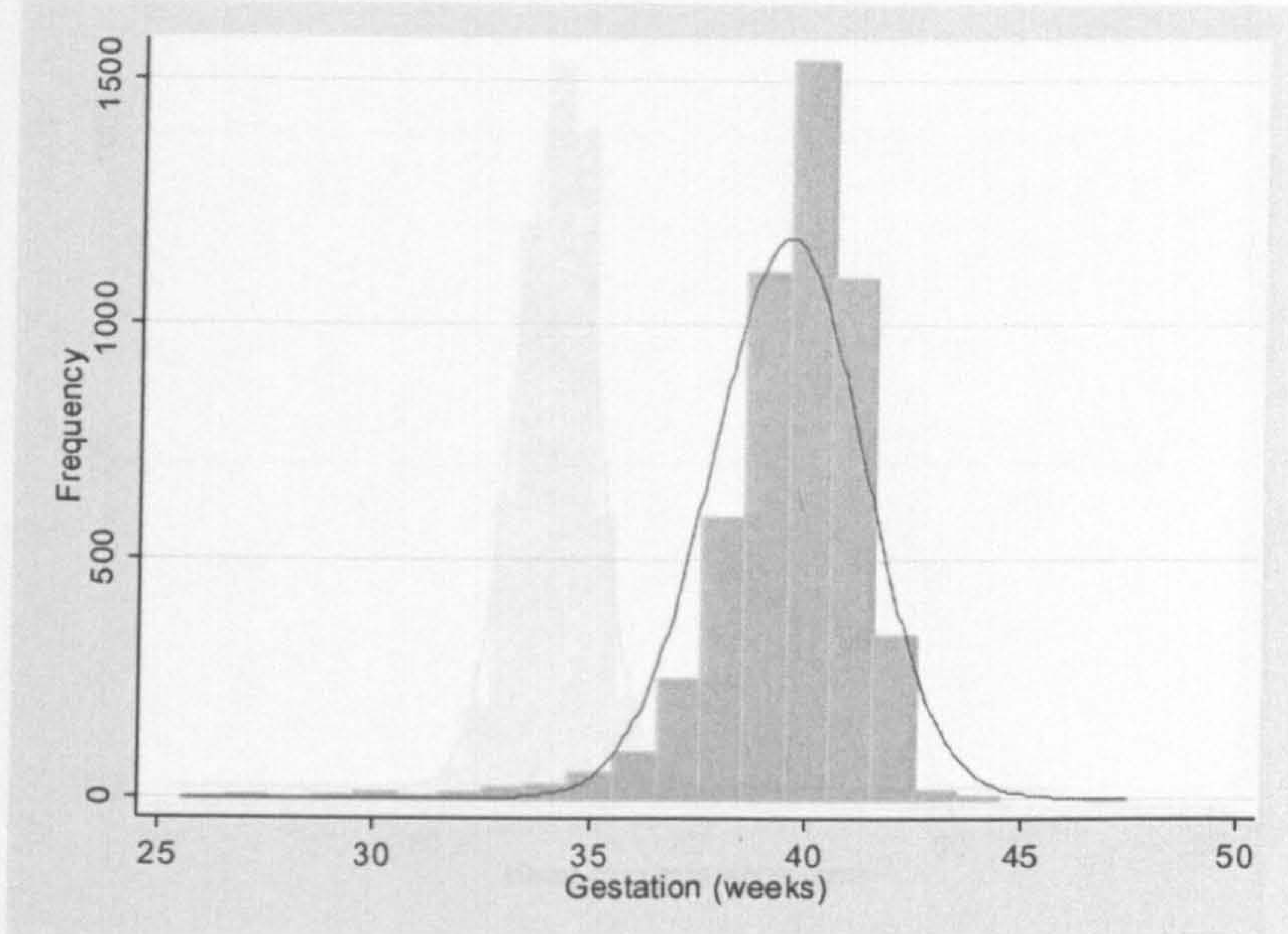
8.5.1 Participants

A total of 11,952 children were invited to participate in the 11-year clinic. Of these, 7,159 (60%) attended the clinic and 6,622 (93%) agreed to wear an Actigraph. Of the children who agreed to participate 5,595 (85%) returned Actigraphs that satisfied the validity criteria [1]. See section 8.1.3 and Table 8.4 for a fuller description of the participants. Multiple births, totalling 144, were excluded from the analyses to rule out non-independence in the data. The sample consisted of 5,451 children (2,593 boys and 2,858 girls) with a mean age of 11.8 years.

8.5.2 Distribution of exposure variables

Distributions for each of the variables used in these analyses are shown in Figures 8.15 to 8.26 and Tables 8.13 to 8.30. This is repeated from Section 5.2, with the sample restricted to those with physical activity data available. Summary variables for the original sample and restricted to those with physical activity data are shown in the boxes beside each histogram for comparison. The N for each of these variables is the number available from the sample of 5451 children. Some of the categorical variables were collapsed into smaller numbers of categories due to insufficient numbers in each category or in order to allow a comparison between similar variables at different time points. This will be highlighted in the following section where categories differ from those presented in section 5.3.

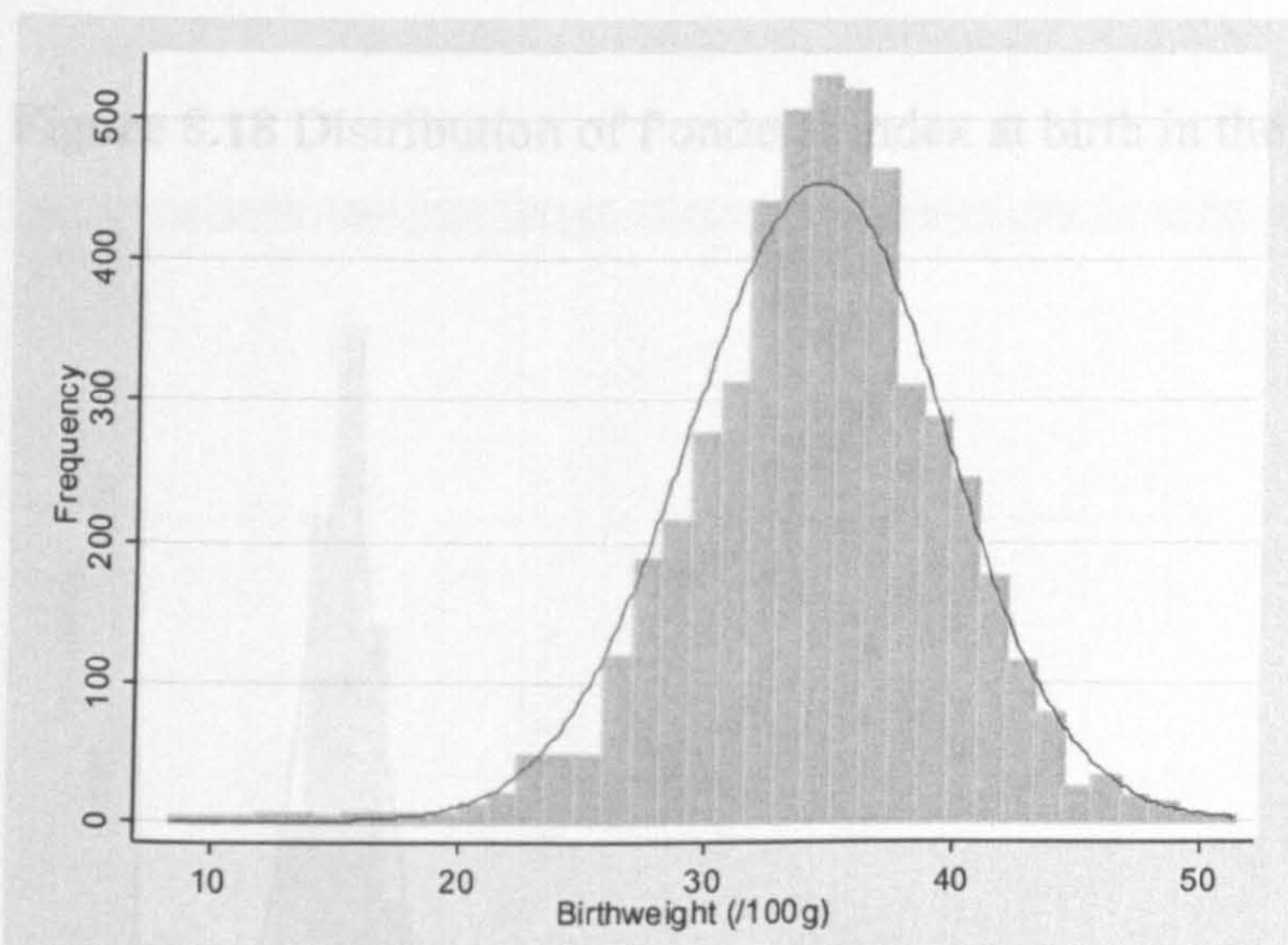
Figure 8.15 Distribution of gestational age in determinants study



N=5190
Missing =261
Mean (SD) 39.5 (1.8)
Median (IQR) 40 (39, 41)

N=13978
Missing =365
Mean (SD) 39.4 (1.9)
Median (IQR) 40 (39, 41)

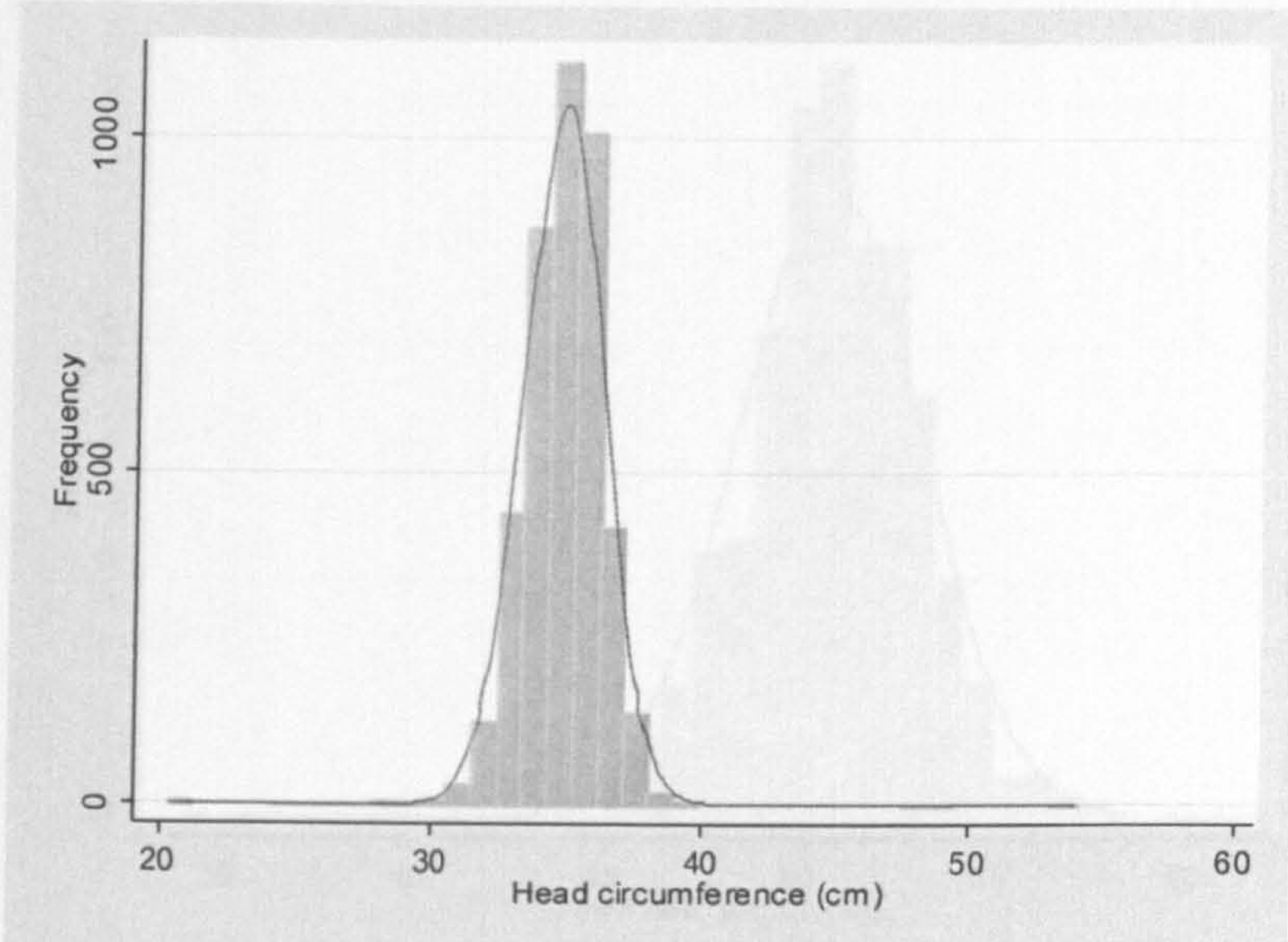
Figure 8.16 Distribution of birthweight (100g) in determinants study



N=5121
Missing =330
Mean (SD) 34.3 (5.2)
Median (IQR) 34.4 (31.2, 37.6)

N=13798
Missing =345
Mean (SD) 3392.0 (559.2)
Median (IQR) 3420 (3090, 3740)

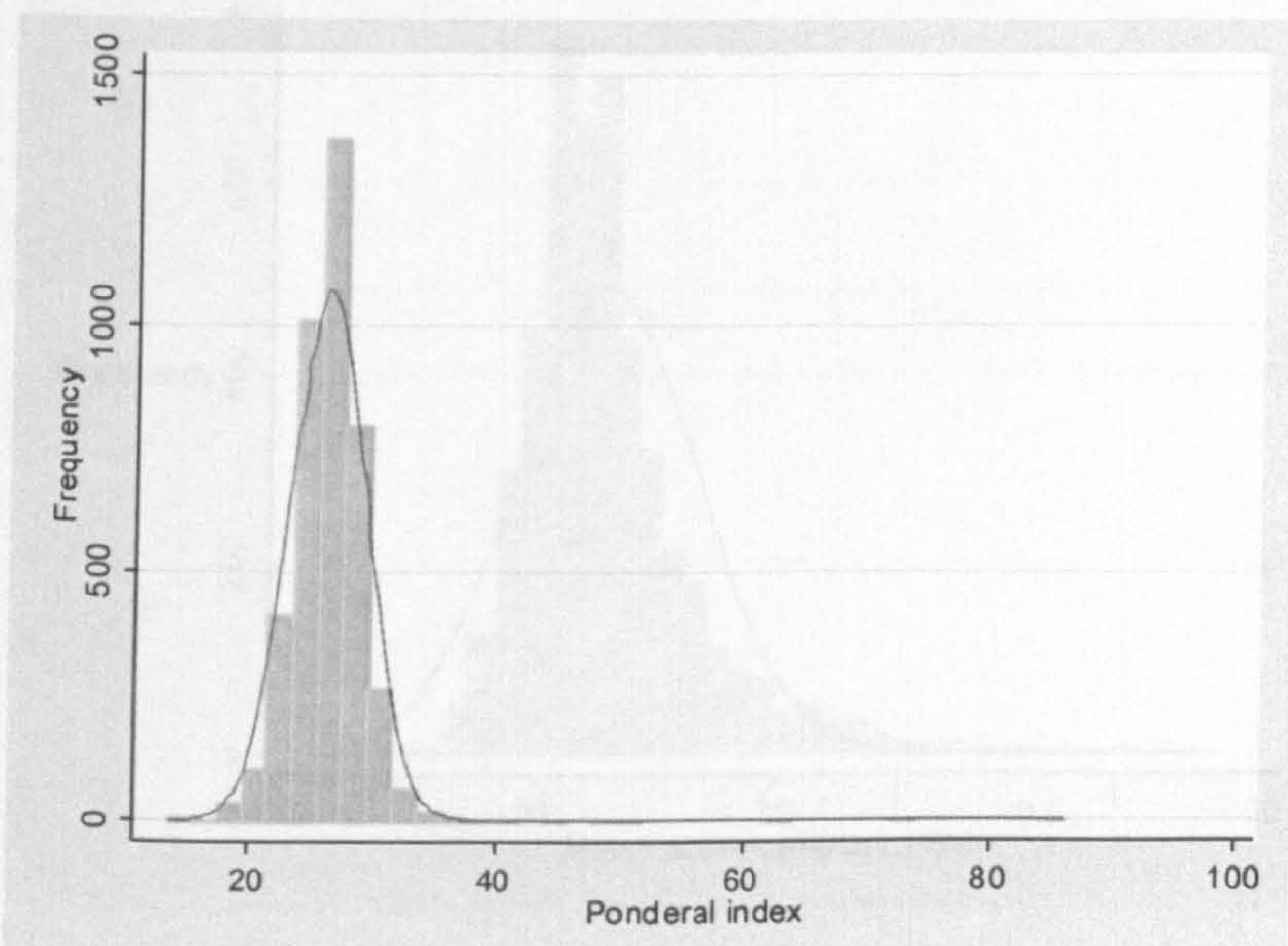
Figure 8.17 Distribution of head circumference at birth in determinants study



N=4193
Missing =1258
Mean (SD) 34.8 (1.5)
Median (IQR) 34.8 (34.0, 35.7)

N=10693
Missing =3650
Mean (SD) 34.8 (1.6)
Median (IQR) 34.8 (33.9, 35.7)

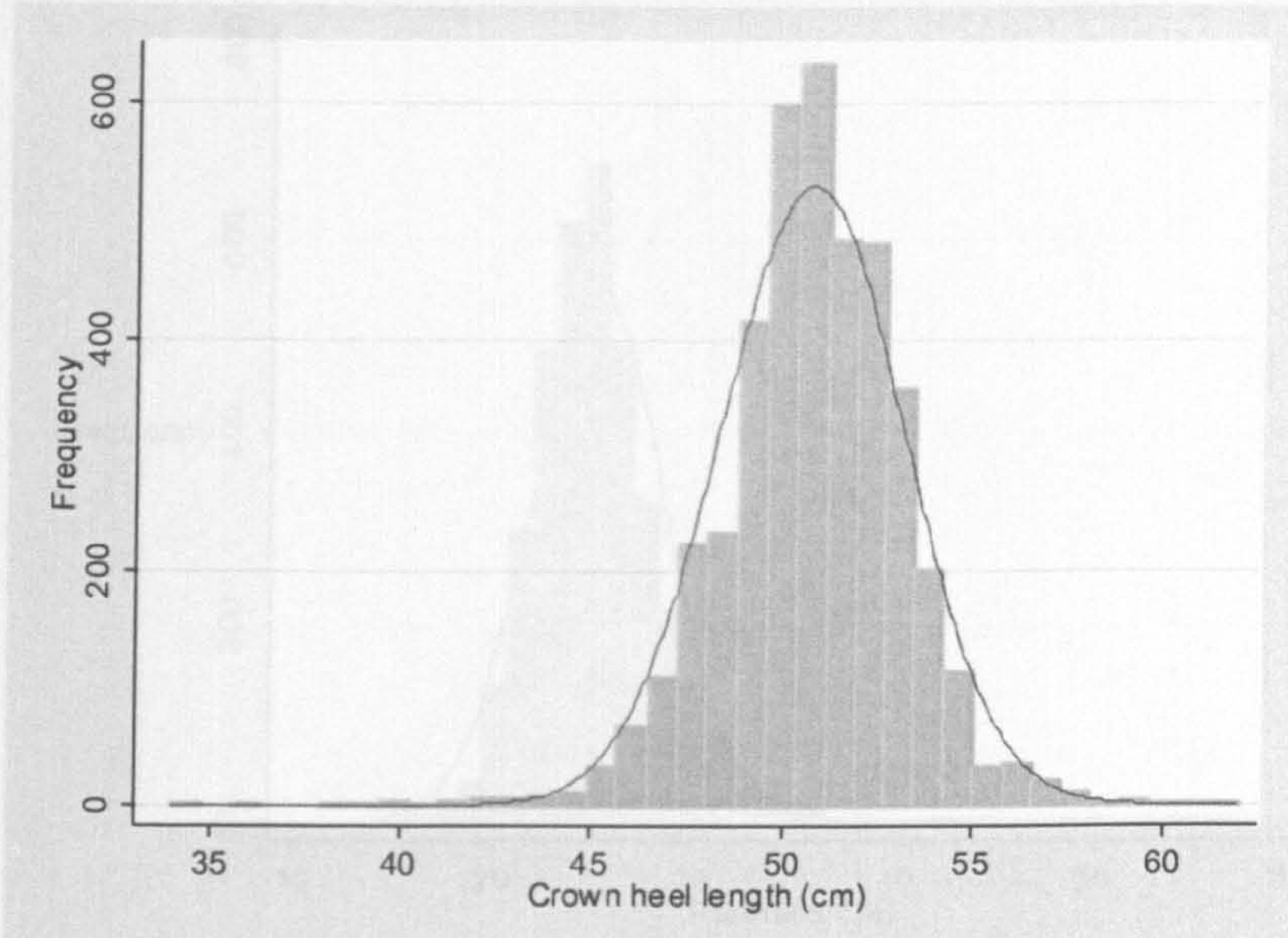
Figure 8.18 Distribution of Ponderal index at birth in the determinants study



N=4094
Missing =1357
Mean (SD) 26.3 (3.1)
Median (IQR) 26.2 (24.7, 27.8)

N=10418
Missing =3925
Mean (SD) 26.3 (3.3)
Median (IQR) 26.2 (24.6, 27.8)

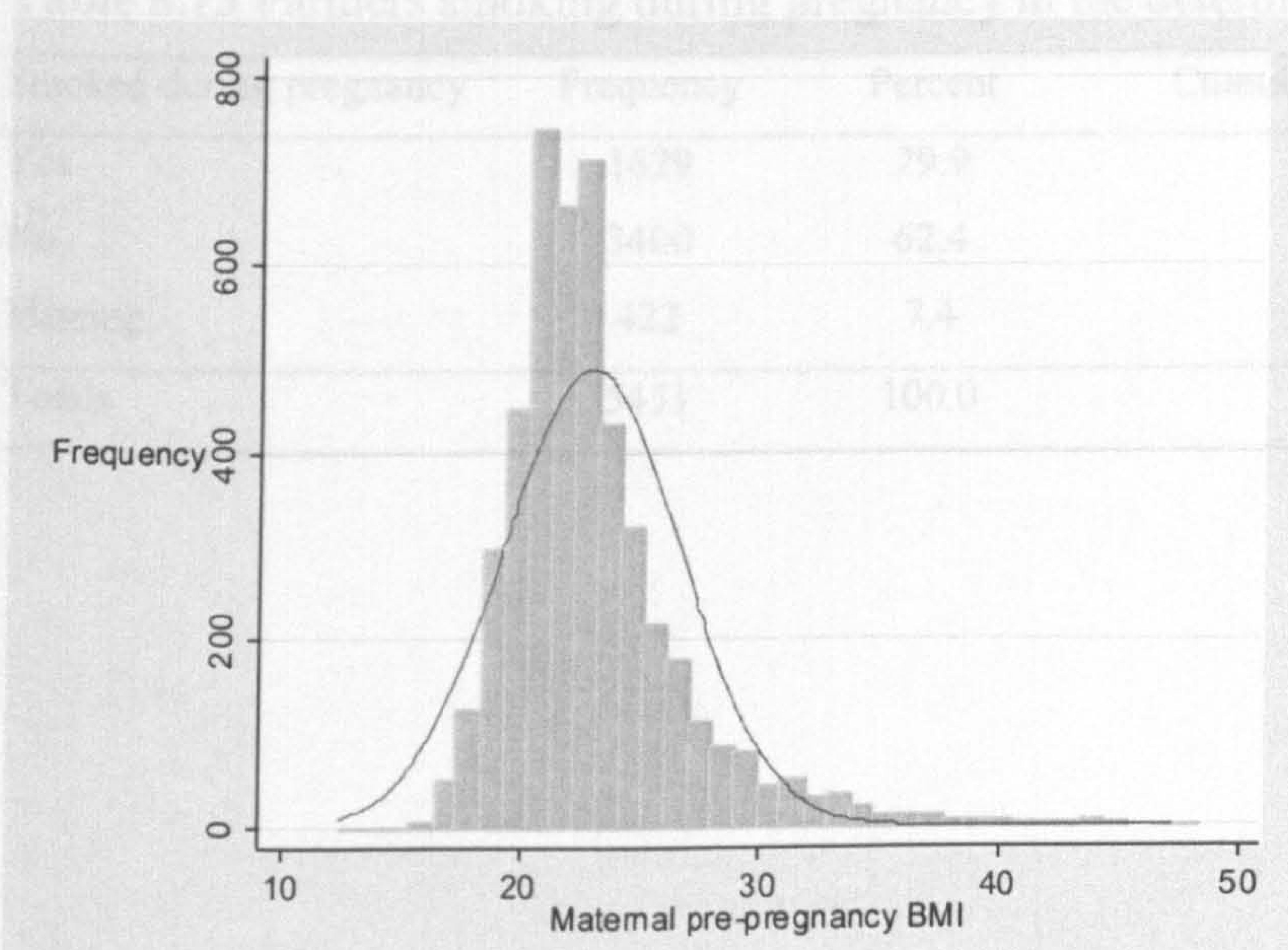
Figure 8.19 Distribution of crown heel length at birth in the determinants study



N=4143
Missing =1308
Mean (SD) 50.7 (2.4)
Median (IQR) 50.8 (49.3, 52.1)

N=10535
Missing =3808
Mean (SD) 50.6 (2.5)
Median (IQR) 50.7 (49.1, 52.0)

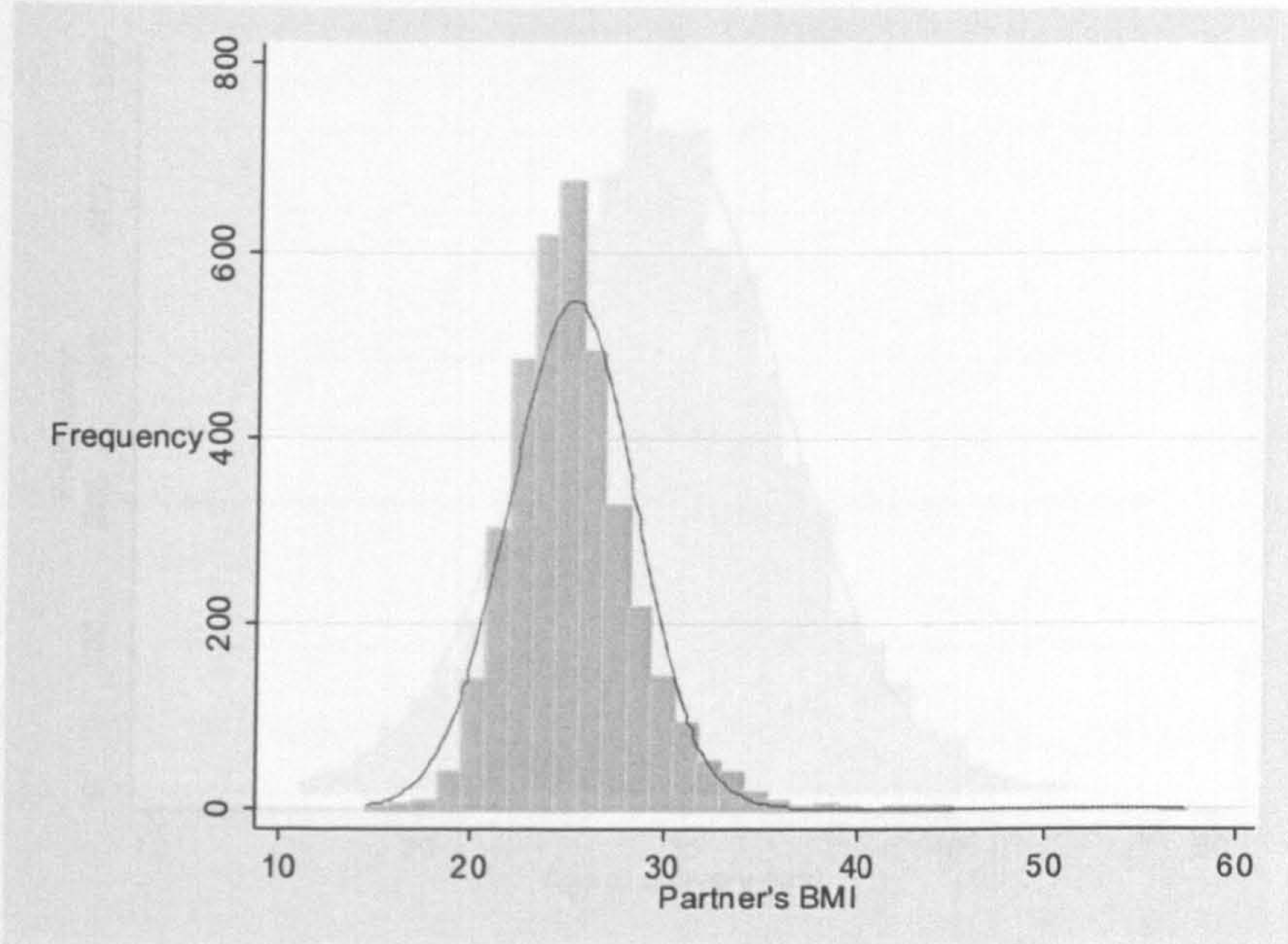
Figure 8.20 Distribution of maternal pre-pregnancy BMI in the determinants study



N=4714
Missing =737
Mean (SD) 22.9 (3.7)
Median (IQR) 22.2 (20.5, 24.2)

N=11535
Missing =2808
Mean (SD) 22.9 (3.8)
Median (IQR) 22.2 (20.5, 24.4)

Figure 8.21 Distribution of partner's BMI in the determinants study



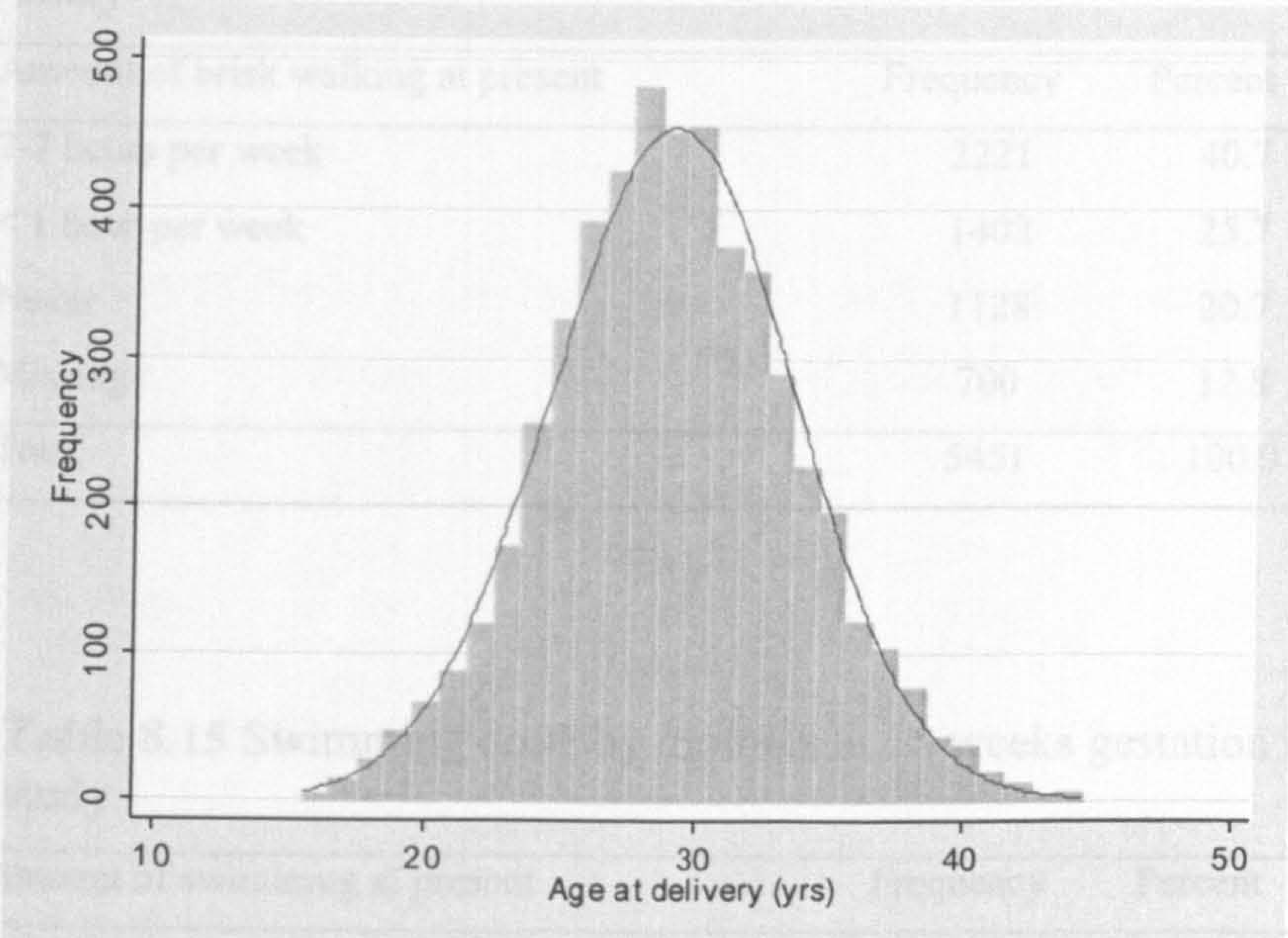
N=3697
Missing =1754
Mean (SD) 25.1 (3.3)
Median (IQR) 24.8 (22.9, 26.8)

N=8340
Missing =6003
Mean (SD) 25.2 (3.3)
Median (IQR) 24.8 (22.9, 27.0)

Table 8.13 Partners smoking during pregnancy in the determinants study

Smoked during pregnancy	Frequency	Percent	Cumulative percent
Yes	1629	29.9	29.9
No	3400	62.4	92.6
Missing	422	7.4	100.0
Totals	5451	100.0	

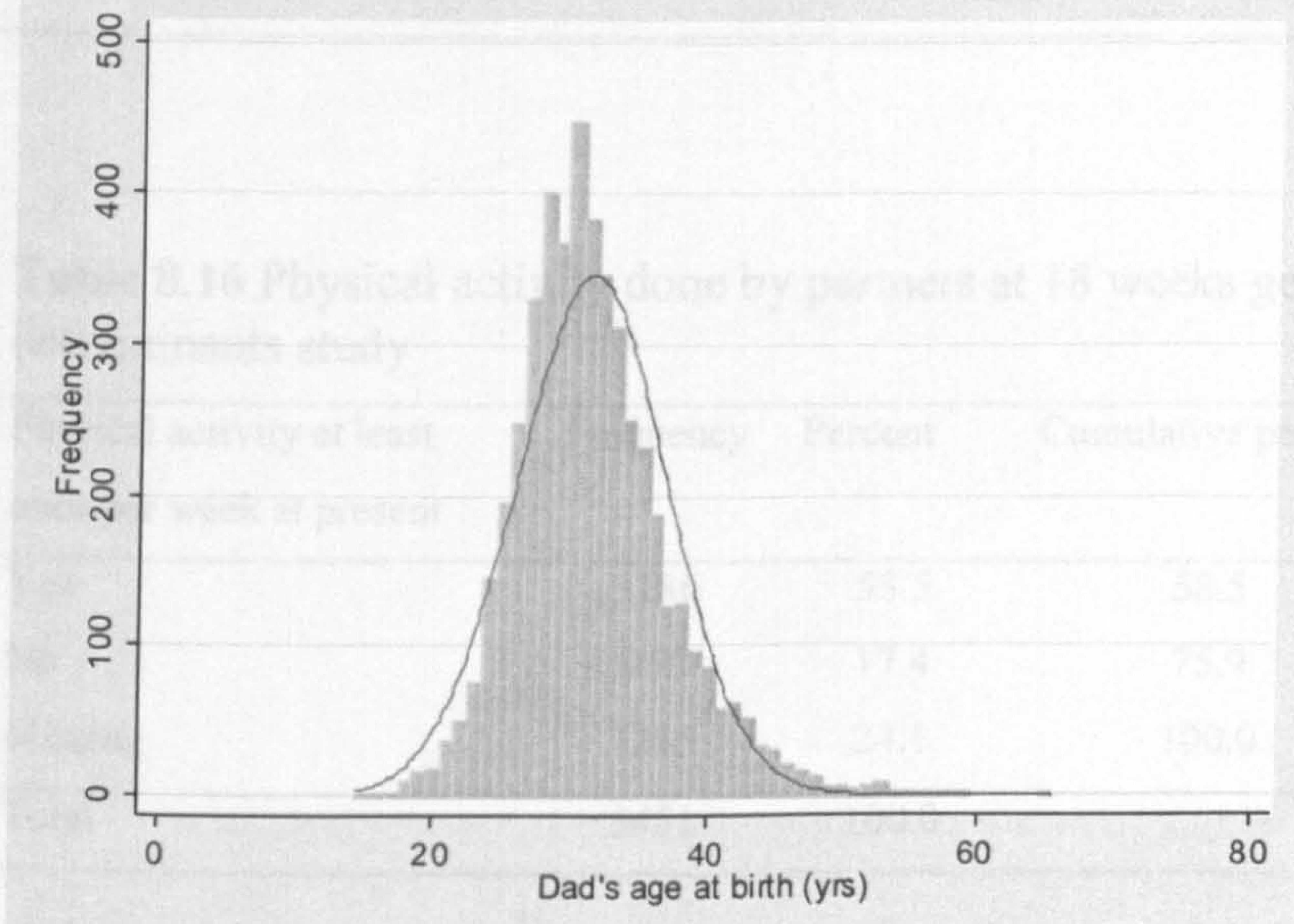
Figure 8.22 Mother's age at birth of child in the determinants study



N=5190
Missing =261
Mean (SD) 29.0 (4.6)
Median (IQR) 29 (26, 32)

N=13978
Missing =365
Mean (SD) 28.0 (5.0)
Median (IQR) 28 (25, 31)

Figure 8.23 Partner's age at birth of child in the determinants study



N=4792
Missing =659
Mean (SD) 31.4 (5.5)
Median (IQR) 31 (28, 34)

N=11673
Missing =2670
Mean (SD) 30.7 (5.7)
Median (IQR) 30 (27, 34)

The variables for brisk walking and swimming were collapsed from four to three categories as some had small numbers in the original categories and to allow comparison between the two variables.

Table 8.14 Brisk walking done by mothers at 18 weeks gestation in the determinants study

Amount of brisk walking at present	Frequency	Percent	Cumulative percent
2-7 hours per week	2221	40.7	40.7
< 1 hour per week	1402	25.7	66.4
Never	1128	20.7	87.2
Missing	700	12.8	100.0
Total	5451	100.0	

Table 8.15 Swimming done by mothers at 18 weeks gestation in the determinants study

Amount of swimming at present	Frequency	Percent	Cumulative percent
2-7 hours per week	503	9.2	9.2
< 1 hour per week	1660	30.5	39.7
Never	2571	47.2	86.9
Missing	717	13.2	100.0
Total	5451	100.0	

Table 8.16 Physical activity done by partners at 18 weeks gestation in the determinants study

Physical activity at least once per week at present	Frequency	Percent	Cumulative percent
Yes	3186	58.5	58.5
No	950	17.4	75.9
Missing	1315	24.1	100.0
Total	5451	100.0	

The question on parity allowed the respondent to give any whole number as an answer so this variable was collapsed to give a smaller number of categories.

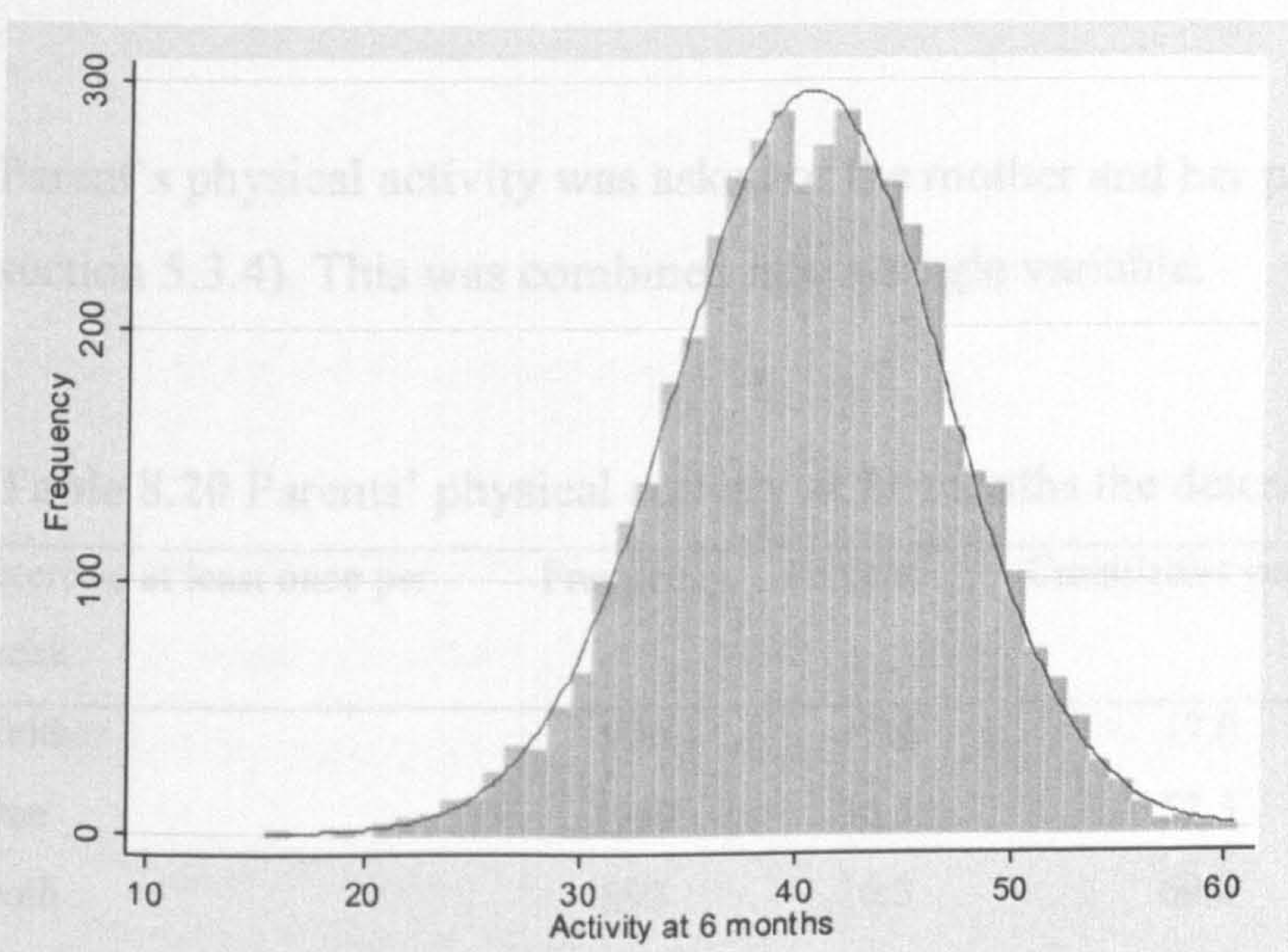
Table 8.17 Parity at 18 weeks gestation in the determinants study

Parity	Frequency	Percent	Cumulative percent
0	2365	43.4	43.4
1	1757	32.23	75.6
≥2	914	16.8	92.4
Missing	415	7.6	100.0
Total	5451	100.0	

Table 8.18 Season of birth in the determinants study

Season of birth	Frequency	Percent	Cumulative percent
Spring	1185	21.7	21.7
Summer	1549	28.4	50.2
Autumn	1487	27.3	77.4
Winter	969	17.8	95.2
Missing	261	4.8	100.0
Total	5451	100.0	

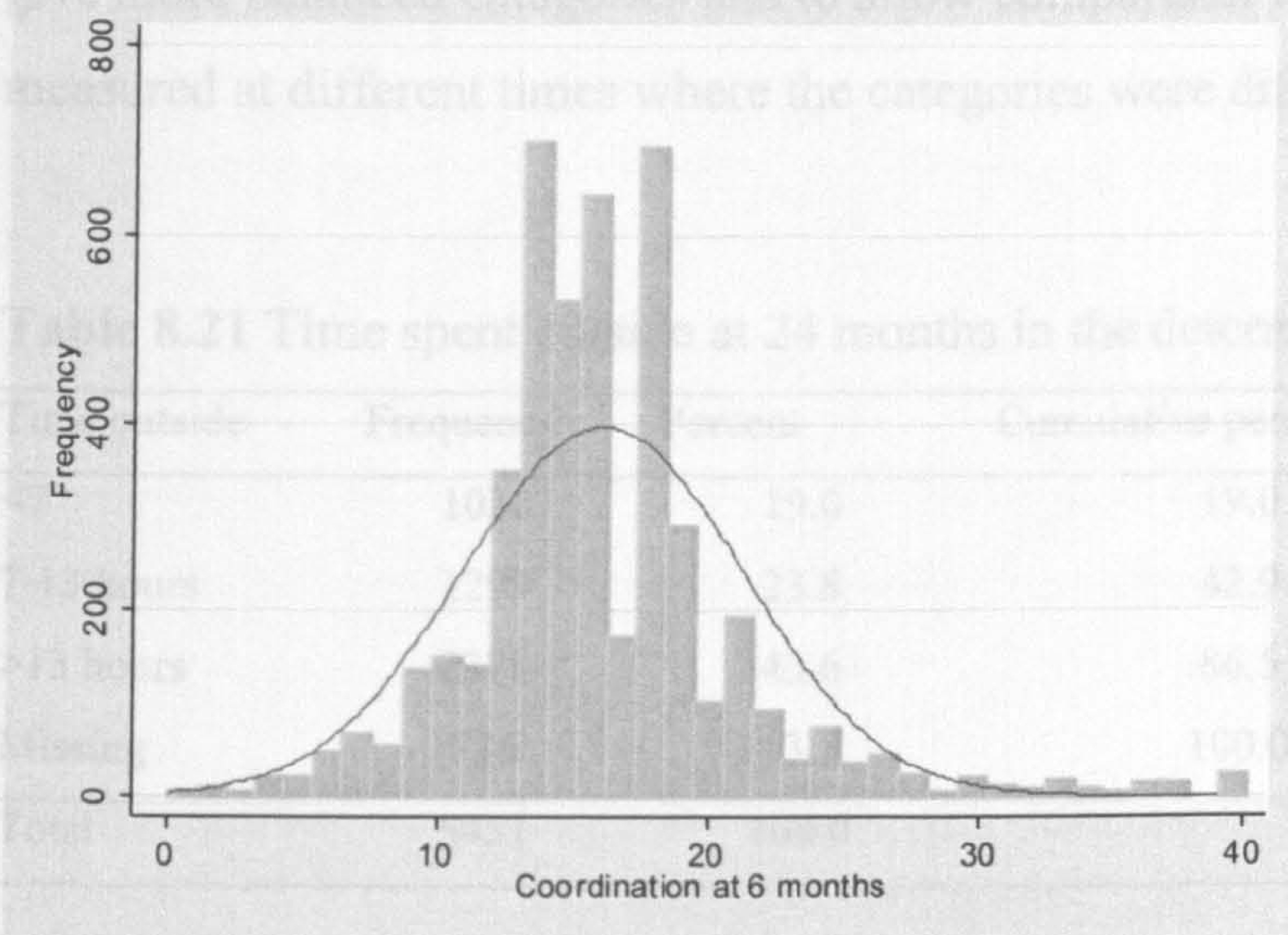
Figure 8.24 Activity score at 6 months in the determinants study, corrected for age and gestation



N=4625
Missing =826
Mean (SD) 40.5 (6.2)
Median (IQR) 41 (36, 45)

N=10502
Missing =4525
Mean (SD) 40.1 (6.3)
Median (IQR) 40 (36, 45)

Figure 8.25 Coordination score at 6 months in the determinants study



N=4788
Missing =663
Mean (SD) 16.1 (5.2)
Median (IQR) 16 (13, 18)

N=11077
Missing =3590
Mean (SD) 16.3 (5.8)
Median (IQR) 16 (13, 18)

Table 8.19 Presence of partner at 8 months in the determinants study

Partner present	Frequency	Percent	Cumulative percent
Yes	4731	86.8	86.8
No	139	2.6	89.3
Missing	581	10.7	100.0
Total	5451	100.0	

Parent's physical activity was asked of the mother and her partner separately (see section 5.3.4). This was combined into a single variable.

Table 8.20 Parents' physical activity at 21 months the determinants study

Exercise at least once per week	Frequency	Percent	Cumulative percent
Neither	926	17.0	17.0
One	1989	36.5	53.5
Both	890	16.3	69.8
Missing	1646	30.2	100.0
Total	5451	100.0	

Time outside at 24 months originally comprised six categories but was collapsed to give more balanced categories and to allow comparison with similar variables measured at different times where the categories were different.

Table 8.21 Time spent outside at 24 months in the determinants study

Time outside	Frequency	Percent	Cumulative percent
<7	1038	19.0	19.0
7-13 hours	1299	23.8	42.9
>13 hours	2378	43.6	86.5
Missing	736	13.5	100.0
Total	5451	100.0	

Table 8.22 Breast-feeding at 6 months in the determinants study

Current breast feeding	Frequency	Percent	Cumulative percent
Yes	1728	31.7	31.7
No	2332	42.8	74.5
Never	825	15.1	89.6
Missing	566	10.4	100.0
Total	5451	100.0	

Time outside at 38 months was collapsed from the original variable, which was derived from the following question:

How much time on average does he/ she spend out of doors:

*On most weekend/weekdays**

Possible responses: *Not at all, less than 1 hour per day, 1-2 hours per day, more than 2 hours per day*

*Derived variable for whole week = (5 x weekday score) + (2 x weekend day score).

This originally gave 16 categories.

Table 8.23 Time spent outside at 38 months in the determinants study

Time outside (hours/week)	Frequency	Percent	Cumulative percent
<7 hours	1936	35.5	35.5
7-13 hours	1117	20.5	56.0
>13 hours	1586	29.1	85.1
Missing	812	14.9	100.0
Total	5451	100.0	

Time outside at 54 months was derived from two questions asking about time outside in summer and winter. These were combined into one variable to allow comparison with other similar variables and then categories were collapsed. (see below for original question).

How much time on average does he/ she spend out of doors:
*In summer weekend/weekdays. In winter weekend/weekdays**
Possible responses: *Not at all, less than 1 hour per day, 1-2 hours per day, more than 3 hours per day*

*Derived variable for whole week = (5 x weekday score) + (2 x weekend day score).

Table 8.24 Time spent outside at 54 months in the determinants study

Time outside (hours/week)	Frequency	Percent	Cumulative percent
<14 hours	968	17.8	17.8
14-20 hours	1550	28.4	46.2
>20 hours	1976	36.3	82.4
Missing	957	17.6	100.0
Total	5451	100.0	

TV viewing at 38 and 54 months was based on the following two questions, respectively:

How much time on average does she spend watching TV:

*On most weekend/weekdays**

Possible responses: *Not at all, less than 1 hour per day, 1-2 hours per day, more than 2 hours per day*

*Derived variable for whole week = (5 x weekday score) + (2 x weekend day score)

*How much time on average does she spend each day:(i) on a weekday (ii) on a weekend day**

Possible responses: *Not at all, less than 1 hour per day, 1-2 hours per day, more than 3 hours per day*

*Derived variable for whole week = (5 x weekday score) + (2 x weekend day score)

These were then dichotomised to allow comparison between the two.

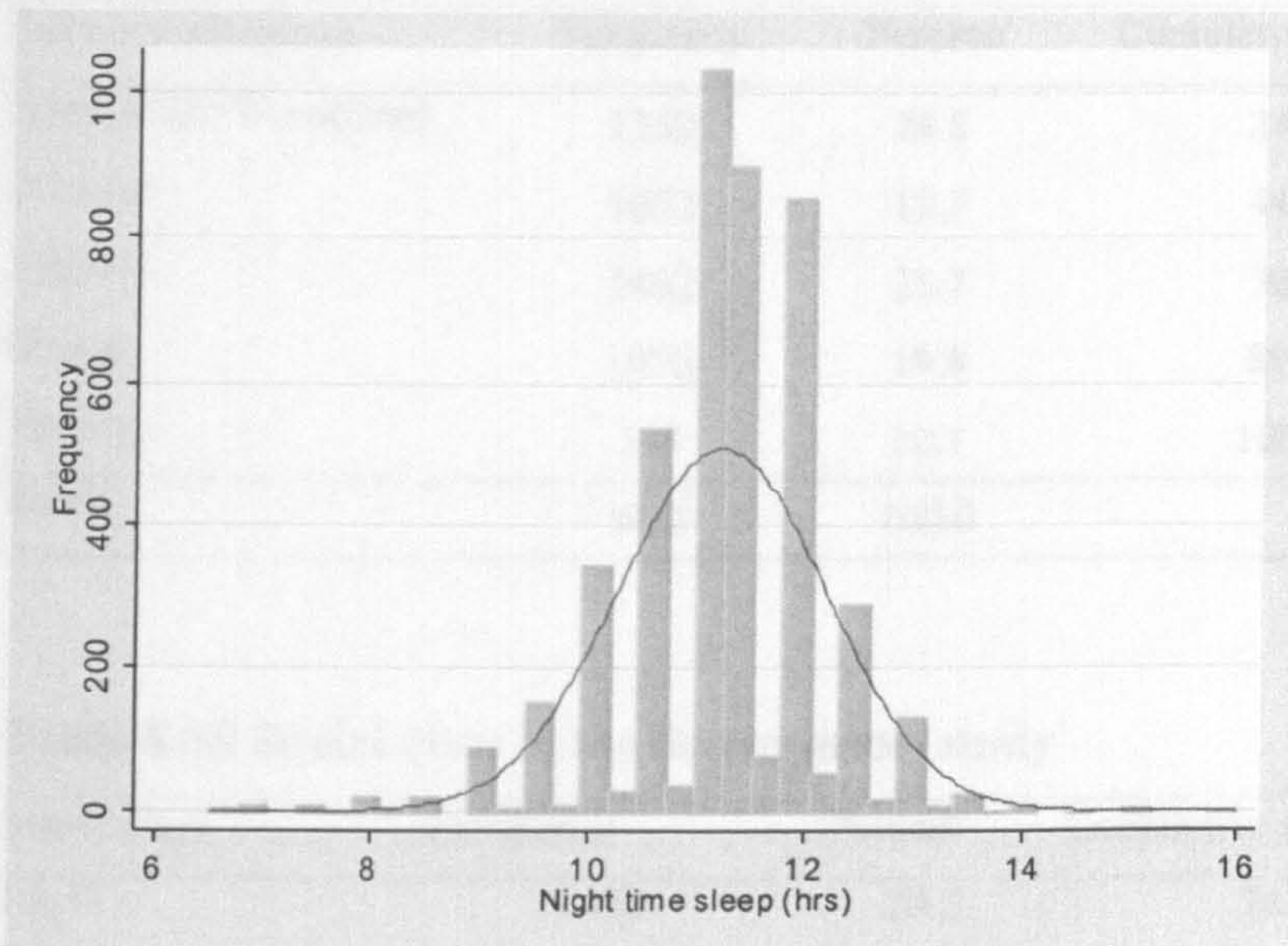
Table 8.25 TV viewing at 38 months in the determinants study

Hours per week	Frequency	Percent	Cumulative percent
<10	3606	66.2	66.2
>10	1050	19.3	85.4
Missing	795	14.6	100.0
Total	5451	100.0	

Table 8.26 TV viewing at 54 months in the determinants study

Hours per week	Frequency	Percent	Cumulative percent
<10	1445	26.5	26.5
>10	3076	56.4	82.9
Missing	930	17.1	100.0
Total	5451	100.0	

Figure 8.26 Hours of night time sleep at 30 months in the determinants study



N=4644
Missing =807
Mean (SD) 11.2 (1.0)
Median (IQR) 11.5 (10.5, 12.0)

N=10059
Missing =4284
Mean (SD) 11.2 (1.0)
Median (IQR) 11.5 (10.5, 12.0)

Table 8.27 Gender in the determinants study

Gender	Frequency	Percent	Cumulative percent
Male	2593	47.6	47.6
Female	2858	52.4	100.0
Missing	–	–	–
Total	5451	100.0	

Table 8.28 Mother's education in the determinants study

Mother's education	Frequency	Percent	Cumulative percent
None/ CSE/ Vocational	1063	19.5	19.5
O Level	1798	33.0	52.5
A level	1343	24.6	77.1
Degree	825	15.1	92.3
Missing	422	7.7	100.0
Totals	5451	100.0	

Table 8.29 Partner's education in the determinants study

Partner's education	Frequency	Percent	Cumulative percent
None/ CSE/ Vocational	1350	24.8	24.8
O Level	1072	19.7	44.4
A level	1402	25.7	70.2
Degree	1078	19.8	89.9
Missing	549	10.1	100.0
Totals	5451	100.0	

Table 8.30 Social class in the determinants study

Social class	Frequency	Percent	Cumulative percent
I & II	1428	26.2	26.2
III NM	1308	24.0	50.2
M	1279	23.5	73.7
IV&V	791	14.5	88.2
Missing	645	11.8	100.0
Totals	5451	100.0	

NM = non-manual, M=manual

8.6 Determinants of physical activity

Tables 8.31 to 8.34 show the associations between exposure variables and counts per minute for each model for each of the suggested critical periods. Results were similar after excluding children who reported swimming or cycling during the measurement period (see Tables 8.36 to 8.39). Results from model three were similar to model one (see Tables 8.40 to 8.43). Results for models one and two with MVPA as the outcome showed a similar pattern to counts per minute as the outcome (see Tables 8.44 to 8.56).

8.6.1 Birth outcomes and physical activity

None of the birth outcomes were associated with physical activity at ages 11 to 12 and this remained unchanged after adjustment for confounding variables (Table 8.31).

8.6.2 Prenatal exposures and physical activity

Few of the prenatal exposures were associated with physical activity (see Table 8.32). Mother's pre-pregnancy BMI and mothers' age at birth of the child were negatively associated with physical activity. Parents' smoking habits during pregnancy, mothers' physical activity and parity were positively associated with physical activity. Season of birth also showed an association with physical activity. The associations for parents' smoking and maternal age attenuated after adjustment for SES, while the associations for maternal physical activity during pregnancy strengthened slightly. Partner's BMI, maternal and partner being obese, partner's age at birth, partner's physical activity and presence of the mother's partner at home were not associated with later physical activity.

8.6.3 Childhood exposures from 0-2 years and physical activity

Table 8.33 shows the associations between childhood exposures from 0-2 years and physical activity. Parental activity and motor coordination were positively associated with later physical activity in the child. Again, these associations tended to be modest and remained after adjustment.

8.6.4 Pre-school exposures (2-5 years) and physical activity

Of the pre-school exposures, only TV viewing at 38 and 54 months showed any clear, negative association, though the associations were small (Table 8.34). There was little evidence that the other proxy measures of physical activity, time spent outside at 38 and 54 months, were associated with later physical activity.

8.6.5 Interactions

There was evidence of interaction in only two of the exposure variables so the results are presented for the analyses of boys and girls combined. Gender*brisk walking and gender*motor coordination both showed evidence of effect modification (P= 0.020 and P=0.008, respectively). Table 8.35 shows the analyses for boys and girls separately where the exposure variable was modified by gender.

Table 8.31 Associations between birth outcomes and counts per minute in children aged 11 to 12 years

	Model 1				Model 2			
Exposure	N	Regression coefficient[a]	95% CI	P	N	Regression coefficient[a]	95% CI	P
Birthweight (100g)[b]	5058	-2.1	-6.7, 2.6	0.383	4671	-0.4	-6.3, 5.5	0.893
Ponderal index (Kg/m^3)[c]	4045	1.3	-3.4, 6.0	0.600	3738	1.0	-3.8, 5.9	0.670
Head circumference (cm)[d]	4144	-5.2	-10.8, 0.3	0.063	3834	-3.5	-9.2, 2.2	0.233
Heel-crown length (cm)[e]	4094	-3.6	-9.4, 2.1	0.217	3786	-1.9	-7.9, 4.0	0.521
Gestation (weeks)[f]	5127	-1.3	-6.1, 3.5	0.599	4739	-2.4	-7.7, 2.9	0.376

Model 1 adjusted for age and gender. Model 2 adjusted for age, gender, and parental social class by occupation and mother's education

[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable. [b]SD=5.2; [c]SD=3.1; [d]SD=1.5; [e]SD=2.4; [f]SD=1.8

Table 8.32 Associations between prenatal exposures and counts per minute in children aged 11 to 12 years

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
Maternal BMI (Kg/m^2)[a]	4657	-3.2	-8.3, 1.9	0.214	4394	-5.2	-10.4, 0.1	0.053
Maternal non-smoking vs	3827				3757			
smoking	698	28.0	14.2, 48.1	<0.001	664	19.0	4.7, 33.0	0.009
Partner non-smoking during	3360				3200			
pregnancy vs smoking	1610	20.1	10.0, 30.2	<0.001	1456	14.2	3.4, 25.0	0.010
Maternal age at birth (years)	5127	-11.5	-16.1, -6.8	<0.001	4739	-7.9	-13.1, -2.7	0.003
Maternal brisk walking (never as baseline)	1113				1041			
<1 hr/week	1384	-2.0	-15.1, 11.2		1339	5.0	-8.5, 18.5	
≥2 hrs/week	2199	12.4	0.3, 24.4	0.022[b]	2103	17.7	5.3, 30.1	0.009[b]
Maternal swimming (never as baseline)	2538				2399			
< 1hr/week	1643	13.2	2.8, 23.6		1589	21.5	10.9, 32.2	
≥2 hrs/week	498	20.0	3.6, 36.4	0.008[b]	485	24.2	7.8, 40.7	<0.001[b]
Parity (0 as baseline)	2331				2183			

Table 8.32 Associations between prenatal exposures and counts per minute in children aged 11 to 12 years

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
1	1739	4.1	-6.1, 14.4		1637	2.9	-7.6, 13.4	
2 +	905	26.1	12.6, 39.6	<0.001[b]	828	21.2	7.1, 35.3	0.012[b]
Season of birth[c] (Spring as baseline)	1174				1089			
Summer	1522	15.7	3.2, 28.1		1420	16.7	4.0, 29.5	
Autumn	1469	31.9	19.1, 44.7		1337	34.1	20.8, 47.5	
Winter	962	33.4	20.0, 46.8	0.001	893	34.7	21.0, 48.5	0.003

Model 1 adjusted for age and gender. Model 2 adjusted for age, gender, parental social class by occupation and mother's education.
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable (SD=3.7)
[b]P for linear trend
[c]Winter= December, January, February; Spring= March, April, May; Summer= June, July, August; Autumn= September, October, November. Additionally adjusted for season of measurement.

Table 8.33 Associations between early childhood exposures (0-2 years) and counts per minute in children aged 11 to 12 years

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
Activity at 6 months[ab]	4574	-2.1	-7.0, 2.7	0.389	4303	-1.5	-6.5, 3.5	0.558
Motor coordination at 6 months[ac]	4736	5.3	0.1, 10.5	0.045	4452	5.8	0.25, 11.3	0.041
Partner at 8 months? Yes vs	4675				4422			
no	138	23.6	-3.4, 50.5	0.086	103	9.5	-21.5, 40.5	0.547
Parents activity at 21 months. Neither active as baseline	917				866			
Either active	1968	29.4	16.2, 42.5		1876	28.5	15.2, 41.8	
Both active	881	31.5	16.1, 46.8	<0.001[a]	844	33.5	17.8, 49.3	<0.001[a]
Time outside at 24 months (<7 hrs/wk as baseline)	1026				946			
7-13 hrs/wk	1284	-15.5	-29.1, -1.8		1224	-12.9	-27.1, 1.2	
>13 hrs/wk	2349	-8.5	-21.0, 3.9	0.085[a]	2211	-6.6	-19.5, 6.4	0.196[d]
Breast feeding 6 months (still	1703				1629			

Table 8.33 Associations between early childhood exposures (0-2 years) and counts per minute in children aged 11 to 12 years, continued

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
breastfeeding as baseline)								
Yes, stopped	2309	7.2	-.3.3, 17.7		2157	-1.3	-12.4, 9.8	
Never	817	10.9	-3.2, 25.0	0.238[a]	749	-5.9	-21.5, 9.6	0.749[d]

Model 1 adjusted for age and gender. Model 2 adjusted for age, gender, parental social class by occupation and mother's education.
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable [b]SD=6.3; [c]SD=5.2
[d]P for linear trend

Table 8.34 Associations between pre-school exposures (2-5 years) and counts per minute in children aged 11 to 12 years

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
Time outside at 38 months (<7 hrs as baseline)	1916				1810			
7-13 hrs/wk	1101	-4.1	-16.8, 8.5		1043	-4.4	-17.4, 8.6	
>13 hrs/wk	1569	-5.6	-16.8, 5.5	0.588[a]	1464	-10.2	-21.8, 1.5	0.230[b]
Time outside at 54 months (<14 hours/week as baseline)	952				894			
14-20 hours/week	1531	14.2	0.7, 27.6		1439	9.0	-4.9, 22.9	
>20 hours/week	1956	10.6	-2.4, 23.5	0.112[a]	1849	4.6	-8.8, 17.9	0.436[b]
TV viewing at 38 months (<10, >10hours/week)	3566 1037	-6.1	-18.0, 5.9	0.318	3367 967	-12.4	-24.9, 0.1	0.051
TV viewing at 54 months (<10, >10 hours/week)	1432 3035	-4.7	-15.0, 5.7	0.375	1354 2853	-11.0	-21.8, -0.2	0.046
Sleep at 30 months (hours/night)[a]	4589	3.0	-1.8, 7.8	0.218	4310	-0.6	-5.8, 4.7	0.837

Model 1 adjusted for age and gender. Model 2 adjusted for age, gender, parental social class by occupation and mother's education
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable; SD=0.96. [b]P for linear trend

Table 8.35 Associations between exposure variables and counts per minute where there is evidence of effect modification by gender

	Boys				Girls			
Exposure	N	Standardised coefficient	95% CI	P	N	Standardised coefficient	95% CI	P
Maternal brisk walking (never as baseline)	517				596			
<1 hr/week	671	-0.1	-21.5, 21.2		713	-4.1	-20.1, 12.0	
≥2 hrs/week	1074	-0.6	-19.9, 18.7	0.998[a]	1125	24.4	9.4, 39.4	<0.001[a]
Motor coordination[b]	2266	-1.6	-9.6, 6.5	0.703	2470	11.6	4.9, 18.4	0.001

Adjusted for age
[a] P for linear trend
[b] Standardised regression coefficient - change in counts per minute per SD of exposure variable; SD= 5.24

Tables 8.36 to 8.39 show the results for children who reported no swimming or cycling during the measurement period. Results are similar to the main results.

Table 8.36 Associations between birth outcomes and counts per minute in children aged 11 to 12 years

	Model 1				Model 2			
Exposure	N	Regression coefficient[a]	95% CI	P	N	Regression coefficient[a]	95% CI	P
Birthweight (100g)[b]	3670	0.7	-5.9, 7.2	0.839	3390	1.5	-5.4, 8.4	0.664
Ponderal index (Kg/m^3)[c]	2913	-2.1	-7.2, 2.9	0.410	2693	-2.4	-7.7, 2.8	0.363
Head circumference (cm)[d]	2977	-6.7	-12.9, -0.5	0.033	2755	-4.9	-11.4, -1.5	0.133
Crown-heel length (cm)[e]	2944	-0.1	-6.7, 6.6	0.983	2723	2.0	-4.9, 8.9	0.571
Gestation (weeks)[f]	3715	2.0	-3.7, 7.7	0.497	3434	1.3	-5.0, 7.6	0.690

Model 1 adjusted for age and gender. Model 2 adjusted for age, gender, and parental social class by occupation and mother's education
aStandardised regression coefficient - change in counts per minute per SD of exposure variable. [b]SD=5.2; [c]SD=3.1; [d]SD=1.4; [e]SD=2.4; [f]SD=1.8

Table 8.37 Associations between prenatal exposures and counts per minute in children aged 11 to 12 years

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
Maternal BMI (Kg/m^2)[a]	3388	-5.0	-10.5, 0.5	0.075	3137	-7.0	-12.6, -1.3	0.015
Maternal non-	2755				2704			
smoking vs smoking	521	22.1	6.9, 37.3	0.004	493	12.6	-3.2, 28.5	0.119
Partner non-	2427				2309			
smoking during pregnancy vs smoking	1170	20.7	9.1, 32.4	0.001	1057	15.6	3.1, 28.2	0.015
Maternal age at birth (years)	3715	-10.8	-16.2, -5.5	<0.001	3434	-8.0	-14.0, -2.0	0.009
Maternal brisk walking (never as baseline)	820				767			
<1 hr/week	997	-0.6	-16.2, 14.9		962	4.5	-11.4, 20.5	
≥2 hrs/week	1585	9.9	-4.3, 24.0	0.202[b]	1517	14.6	-0.0, 29.2	0.103[b]
Maternal swimming (never as baseline)	1862				1757			
< 1hr/week	1184	16.1	3.9, 28.2		1147	24.5	12.1, 46.9	
≥2 hrs/week	339	31.5	11.6, 51.5	0.001[b]	332	27.3	17.3, 57.3	<0.001[b]

Table 8.37 Associations between prenatal exposures and counts per minute in children aged 11 to 12 years, contd

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
Parity (0 as baseline)	1681				1577			
1	1263	7.6	-4.4, 19.6		1185	5.7	-6.6, 18.1	
2 +	664	29.9	14.1, 45.6	0.001[b]	604	25.2	8.6, 41.7	0.012[b]
Season of birth[c] (Spring as baseline)	915				851			
Summer	1103	13.4	-0.8, 27.7		1031	14.1	-0.5, 28.8	
Autumn	992	25.5	10.3, 40.6		901	27.2	11.4, 43.1	
Winter	705	33.9	18.5, 42.2	0.001	651	32.3	16.6, 48.1	0.003

Model 1 adjusted for age and gender. Model 2 adjusted for age, gender, parental social class by occupation and mother's education.
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable (SD=3.9)
[b] P for linear trend
[c]Winter= December, January, February; Spring= March, April, May; Summer= June, July, August; Autumn= September, October, November. Additionally adjusted for season of measurement.

Table 8.38 Associations between early childhood exposures (0-2 years) and counts per minute in children aged 11 to 12 years

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
Activity at 6 months[ab]	3314	-2.7	-8.3, 3.0	0.356	3126	-2.9	-8.7, 2.9	0.334
Motor coordination at 6 months[ac]	3418	7.0	0.7, 13.3	0.029	3215	7.1	0.3, 113.9	0.040
Partner at 8 months? Yes vs	3363				3186			
no	107	29.4	-1.7, 60.4	0.064	81	19.9	-15.9, 55.7	0.275
Parents activity at 21 months. Neither active as baseline	688				646			
Either active	1422	24.4	9.1, 39.7		1364	22.7	7.0, 38.4	
Both active	620	23.2	5.2, 41.2	0.005[d]	592	22.6	4.1, 41.1	0.012[d]
Time outside at 24 months (<7 hrs/wk as baseline)	747				685			
7-13 hrs/wk	944	-20.0	-36.0, -3.9		897	-16.8	-33.5, -0.1	
>13 hrs/wk	1684	-9.5	-24.2, 5.2	0.047[d]	1591	-6.2	-29.6, 9.2	0.113[d]
Breast feeding 6 months (still	1242				1195			

***Table 8.38** Associations between early childhood exposures (0-2 years) and counts per minute in children aged 11 to 12 years, contd*

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
breastfeeding as baseline)								
Yes, stopped	1636	-3.1	-16.0, 10.0		1520	-3.0	-16.0, 10.0	
Never	615	-3.8	-21.6, 14.0	0.879[d]	570	-3.8	-21.6, 14.0	0.879[d]

Model 1 adjusted for age and gender. Model 2 adjusted for age, gender, parental social class by occupation and mother's education.
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable [b]SD=6.3; [c]SD=5.2
[d]P for linear trend

Table 8.39 Associations between pre-school exposures (2-5 years) and counts per minute in children aged 11 to 12 years

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
Time outside at 38 months (<7 hrs as baseline)	1373				1298			
7-13 hrs/wk	777	1.3	-13.8, 16.4		737	0.9	-14.6, 6.4	
>13 hrs/wk	1158	-4.8	-17.8, 8.1	0.678[b]	1078	-4.8	-21.3, 5.8	0.445[b]
Time outside at 54 months (<14 hours/week as baseline)	687				649			
14-20 hours/week	1084	11.2	-4.7, 27.0		1019	7.0	-9.4, 23.5	
>20 hours/week	1441	11.7	-3.5, 26.8	0.281[b]	1362	6.7	-9.0, 22.4	0.654[b]
TV viewing at 38 months (<10,	2544				2403			
>10hours/week)	773	-7.3	-20.9, 6.4	0.299	719	-15.2	-29.5, -0.9	0.038
TV viewing at 54 months (<10,	1008				949			
>10 hours/week)	2219	-6.7	-19.0, 5.6	0.284	2094	-11.9	-24.7, 0.9	0.068
Sleep at 30 months (hours/night)[a]	3322	4.1	-1.6, 9.7	0.155	3118	2.0	-4.1, 8.2	0.518

Model 1 adjusted for age and gender. Model 2 adjusted for age, gender, parental social class by occupation and mother's education
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable; SD=0.96. [b]P for linear trend

Tables 8.40 to 8.43 show Model 3 for counts per minute. Model 3 is adjusted as model one but restricted to those included in Model 2. Results are similar to Model 1.

Table 8.40 Associations between birth outcomes and counts per minute in children aged 11 to 12 years

		Model 3		
Exposure	N	Regression coefficient	95% CI	P
Birthweight (100g) [b]	4671	-0.7	-6.4, 4.9	0.798
Ponderal index (Kg/m3) [c]	3738	1.2	-3.6, 6.0	0.636
Head circumference (cm) [d]	3834	-4.5	-10.2, 1.1	0.117
Crown-heel length (cm) [e]	3786	-2.8	-8.6, 3.1	0.353
Gestation (weeks) [e]	4739	-2.3	-7.4, 2.7	0.363

Model 3 adjusted for age and gender, restricted to those in Model 2.
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable. [b]SD=5.1; [c]SD=3.0; [d]SD=1.5; [e]SD=2.4; [f]SD=1.7

Table 8.41 Associations between prenatal exposures and counts per minute in children aged 11 to 12 years

		Model 3		
Exposure	N	Regression coefficient	95% CI	P
Maternal BMI (Kg/m^2)[a]	4394	-3.2	-8.4, 2.0	0.230
Maternal non-smoking vs	3757			
smoking	664	27.5	13.4, 41.7	<0.001
Partner non-smoking during pregnancy	3200			
vs smoking	1456	19.9	9.4, 30.5	<0.001
Maternal age at birth (years)	4739	-11.9	-16.7, -7.2	<0.001
Maternal brisk walking (never as baseline)[a]	1041			
<1 hr/week	1339	-0.1	-13.6, 13.3	
≥2 hrs/week	2103	13.8	1.5, 26.2	0.021[b]
Maternal swimming (never as baseline)	2399			
< 1hr/week	1589	16.1	5.5, 26.7	
≥2 hrs/week	485	20.5	4.0, 37.0	0.003
Parity (0 as baseline)	2183			
1	1637	4.3	-6.2, 14.9	
2 +	828	24.7	10.5, 38.9	0.003

Table 8.41 Associations between prenatal exposures and counts per minute in children aged 11 to 12 years, contd

	Model 3			
Exposure	N	Regression coefficient	95% CI	P
Season of birth[c] (Spring as baseline)	1089			
Summer	1420	17.2	4.4, 30.0	
Autumn	1337	35.2	21.9, 48.6	
Winter	893	36.0	22.1, 49.8	<0.001

Model 3 adjusted for age and gender, restricted to those in Model 2.
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable (BMI SD=3.7; maternal age SD=4.4)
[b]P for linear trend
[c]Winter= December, January, February; Spring= March, April, May; Summer= June, July, August; Autumn= September, October, November. Additionally adjusted for season of measurement.

Table 8.42 Associations between early childhood exposures (0-2 years) and counts per minute in children aged 11 to 12 years

	Model 3			
Exposure	N	Regression coefficient	95% CI	P
Activity at 6 months[ab]	4303	-2.5	-7.5, 2.5	0.332
Motor coordination at 6 months[ac]	4452	5.3	-0.2, 10.7	0.058
Partner at 8 months? Yes vs	4422			
no	103	16.1	-14.5, 47.5	0.296
Parents activity at 21 months. Neither active as baseline	866			
Either active	1876	29.9	16.6, 43.1	
Both active	844	31.2	15.5, 46.9	<0.001[d]
Time outside at 24 months (<7 hrs/wk as baseline)	946			
7-13 hrs/wk	1224	-16.1	-30.3, 2.0	
>13 hrs/wk	2211	-9.0	-22.0, 4.0	0.082[d]
Breast feeding 6 months (still breastfeeding as baseline)	1629			
Yes, stopped	2157	7.0	-3.8, 17.8	
Never	749	11.0	-3.8, 17.8	0.262[d]

Model 3 adjusted for age and gender, restricted to those in Model 2.
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable [b]SD=6.2; [c]SD=5.1
[d]P for linear trend

Table 8.43 Associations between pre-school exposures (2-5 years) and counts per minute in children aged 11 to 12 years

	Model 3			
Exposure	N	Regression coefficient	95% CI	P
Time outside at 38 months (<7 hrs as baseline)	1810			
7-13 hrs/wk	1043	-3.2	-16.2, 9.8	
>13 hrs/wk	1464	-5.3	-16.9, 6.2	0.655[b]
Time outside at 54 months (<14 hours/week as baseline)	894			
14-20 hours/week	1439	13.7	-0.2, 27.6	
>20 hours/week	1849	9.1	-4.2, 22.4	0.154[b]
TV viewing at 38 months (<10, >10hours/week)	3367			
	967	-4.7	-17.1, 7.6	0.452
TV viewing at 54 months (<10, >10 hours/week)	1354			
	2853	-4.3	-14.9, 6.3	0.431
Sleep at 30 months (hours/night)[a]	4310	4.0	-0.9, 8.9	0.113

Model 3 adjusted for age and gender, restricted to those in Model 2.
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable; SD=0.95. [b]P for linear trend

8.6.8 Associations between exposure variables and MVPA

Models were also run with MVPA as the outcome. A cut-point of 3600 counts per minute was used to define MVPA. The pattern of associations is similar to that for counts per minute. Tables 8.44 to 8.45 show models one and two and the results of interaction tests for the whole sample. The results for model one and two were similar.

Table 8.44 Associations between birth outcomes and MVPA in children aged 11 to 12 years

	Model 1				Model 2			
Exposure	N	Regression coefficient[a]	95% CI	P	N	Regression coefficient[a]	95% CI	P
Birthweight (100g)[b]	5058	0.1	-0.4, 0.6	0.693	4671	0.1	-0.4, 0.6	0.694
Ponderal index (Kg/m^3)[c]	4045	-0.1	-0.5, 0.4	0.813	3738	-0.1	-0.5, 0.3	0.653
Head circumference (cm)[d]	4144	-0.0	-0.5, 0.5	0.995	3834	0.0	-0.5, 0.5	0.927
Crown-heel length (cm)[e]	4094	0.1	-0.4, 0.6	0.712	3786	0.2	-0.4, 0.7	0.549
Gestation (weeks)[f]	5127	0.1	-0.3, 0.5	0.751	4739	-0.1	-0.5, 0.4	0.743

Model 1 adjusted for age and gender. Model 2 adjusted for age, gender, and parental social class by occupation and mother's education
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable. [b]SD=5.2; [c]SD=3.1; [d]SD=1.4; [e]SD=2.4; [f]SD=1.8

Table 8.45 Associations between prenatal exposures and MVPA in children aged 11 to 12 years

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
Maternal BMI (Kg/m^2)[a]	4657	-0.7	-1.1, -0.2	0.003	4394	-0.7	-1.1, -0.2	0.003
Maternal non-smoking vs	3827				3757			
smoking	698	1.5	0.3, 2.7	0.015	664	1.4	0.1, 2.6	0.031
Partner non-smoking during	3360				3200			
pregnancy vs smoking	1610	0.9	0.0, 1.7	0.045	1426	0.8	-0.2, 1.7	0.103
Maternal age at birth (years)	5127	-0.1	-0.5, 0.3	0.579	4739	-0.2	-0.6, 0.3	0.483
Maternal brisk walking (never as baseline)	1113				1041			
<1 hr/week	1384	0.4	-0.7, 1.5		1339	0.7	-0.5, 1.8	
≥2 hrs/week	2199	1.4	0.4, 2.5	0.012[b]	2103	1.6	0.5, 2.6	0.012[b]
Maternal swimming (never as baseline)	2538				2399			
< 1hr/week	1643	1.5	0.6, 2.4		1589	1.8	0.8, 2.7	
≥2 hrs/week	498	1.6	0.3, 3.0	0.002[b]	485	1.7	0.3, 3.1	<0.001[b]

Table 8.45 Associations between prenatal exposures and MVPA in children aged 11 to 12 years, contd

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
Parity (0 as baseline)	2331				2183			
1	1739	1.0	0.1, 1.9		1637	1.0	0.1, 1.9	
2 +	905	2.7	1.6, 3.6	<0.001[b]	828	2.5	1.2, 3.7	<0.001[b]
Season of birth[c] (Spring as baseline)	1174				1089			
Summer	1522	0.7	-0.4, 1.8		1420	0.8	-0.4, 1.9	
Autumn	1469	0.0	-1.1, 1.1		1337	0.2	-1.0, 1.4	
Winter	962	0.8	-0.3, 2.0	0.406	893	1.0	-2.0, 2.2	0.285

Model 1 adjusted for age and gender. Model 2 adjusted for age, gender, parental social class by occupation and mother's education.
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable (SD=3.9)
[b]P for linear trend
[c]Winter= December, January, February; Spring= March, April, May; Summer= June, July, August; Autumn= September, October, November. Additionally adjusted for season of measurement.

Table 8.46 Associations between early childhood exposures (0-2 years) and MVPA in children aged 11 to 12 years

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
Activity at 6 months[ab]	4574	-0.0	-0.4, 0.4	0.873	4303	-0.1	-0.5, 0.3	0.701
Motor coordination at 6 months[ac]	4736	0.5	0.0, 1.0	0.042	4452	0.5	0.0, 1.0	0.033
Partner at 8 months? Yes vs	4675				4422			
no	138	0.9	-1.5, 3.2	0.461	103	1.2	-1.7, 4.0	0.416
Parents activity at 21 months. Neither active as baseline	917				866			
Either active	1968	2.3	1.2, 3.4		1876	2.3	1.1, 3.4	
Both active	881	3.3	2.0, 4.6	<0.001[d]	946	3.3	1.9, 4.6	<0.001[d]
Time outside at 24 months (<7 hrs/wk as baseline)	1026				946			
7-13 hrs/wk	1284	-1.0	-2.1, 0.2		1224	-0.9	-2.1, 0.3	
>13 hrs/wk	2349	0.2	-1.3, 0.9	0.189[d]	2211	-0.1	-1.3, 1.0	0.246

Table 8.46 Associations between early childhood exposures (0-2 years) and MVPA in children aged 11 to 12 years, contd

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
Breast feeding 6 months (still breastfeeding as baseline)	1703				1629			
Yes, stopped	2309	-0.4	-1.3, 0.5		2157	-0.6	-1.5, 0.4	
Never	817	-1.0	-2.2, 0.2	0.286[d]	749	-1.4	-2.7, -0.1	0.112[d]

Model 1 adjusted for age and gender. Model 2 adjusted for age, gender, parental social class by occupation and mother's education.
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable [b]SD=6.3; [c]SD=5.2
[d]P for linear trend

Table 8.47 Associations between pre-school exposures (2-5 years) and MVPA in children aged 11 to 12 years

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
Time outside at 38 months (<7 hrs as baseline)	1916				1810			
7-13 hrs/wk	1101	0.4	-0.7, 1.5		1043	0.4	-0.8, 1.5	
>13 hrs/wk	1596	0.3	-0.6, 1.3	0.704[b]	1464	0.3	-0.7, 1.3	0.730[b]
Time outside at 54 months (<14 hours/week as baseline)	952				894			
14-20 hours/week	1531	0.0	-1.2, 1.2		1439	-0.1	-1.3, 1.1	
>20 hours/week	1956	0.3	-0.8, 1.5	0.754[b]	1849	0.1	-1.1, 1.3	0.875[b]
TV viewing at 38 months (<10,	3566				3367			
>10hours/week)	1037	-0.7	-1.7, 0.3	0.185	967	-0.7	-1.8, 0.4	0.194
TV viewing at 54 months (<10,	1432				1354			
>10 hours/week)	3035	-0.4	-1.2, 0.5	0.421	2853	-0.5	-1.4, 0.4	0.311
Sleep at 30 months (hours/night)[a]	4589	0.2	-0.3, 0.6	0.465	4310	-0.2	-0.7, 0.2	0.341

Model 1 adjusted for age and gender. Model 2 adjusted for age, gender, parental social class by occupation and mother's education
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable; SD=0.96. [b] P for linear trend

Table 8.48 Associations between exposure variables and MVPA where there is evidence of effect modification by gender

	Boys				Girls			
Exposure	N	Standardised coefficient	95% CI	P	N	Standardised coefficient	95% CI	P
Maternal brisk walking (never as baseline)	517				596			
<1 hr/week	671	0.6	-1.3, 2.6		713	0.1	-1.1, 1.4	
≥2 hrs/week	1074	0.2	-1.5, 2.0	0.809[a]	1125	2.6	1.4, 3.7	<0.001[a]
Motor coordination[b]	2266	0.0	-0.1, 0.1	0.931	2470	0.2	0.1, 0.3	0.001
Activity at 6 months[c]	2193	0.1	-0.0, 0.2	0.207	2381	-0.1	-0.1, 0.0	0.050

Adjusted for age
[a] P for linear trend
[b] Standardised regression coefficient - change in counts per minute per SD of exposure variable; SD= 5.3 for boys, 5.1 for girls
[c] Standardised regression coefficient - change in counts per minute per SD of exposure variable; SD= 6.2 for boys, 6.3 for girls

Tables 8.49 to 8.53 show the early life associations with MVPA with swimming and cycling excluded. The results are similar to the main model for MVPA.

Table 8.49 Associations between birth outcomes and MVPA in children aged 11 to 12 years (no swim or cycle)

	Model 1				Model 2			
Exposure	N	Regression coefficient[a]	95% CI	P	N	Regression coefficient[a]	95% CI	P
Birthweight (100g)[b]	3670	0.1	-0.4, 0.7	0.644	3390	0.1	-0.5, 0.7	0.776
Ponderal index (Kg/m^3)[c]	2913	-0.3	-0.8, 0.2	0.209	2693	-0.3	-0.8, 0.1	0.175
Head circumference (cm)[d]	2977	-0.1	-0.7, 0.4	0.657	2755	-0.1	-0.7, 0.4	0.668
Crown-heel length (cm)[e]	2944	0.2	-0.3, 0.8	0.416	2723	0.3	-0.3, 0.9	0.364
Gestation (weeks)[f]	3715	0.3	-0.1, 0.8	0.169	3434	0.3	-0.3, 0.8	0.345

Model 1 adjusted for age and gender. Model 2 adjusted for age, gender, and parental social class by occupation and mother's education
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable. [b]SD=5.2; [c]SD=3.1; [d]SD=1.4; [e]SD=2.4; [f]SD=1.8

Table 8.50 Associations between prenatal exposures and MVPA in children aged 11 to 12 years

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
Maternal BMI (Kg/m^2)[a]	3388	-0.8	-1.2, -0.3	0.002	3137	-0.8	-1.3, -0.4	0.001
Maternal non-	2755				2704			
smoking vs smoking	521	1.1	-0.2, 2.4	0.091	493	1.0	-0.4, 2.4	0.163
Partner non-	2427				2309			
smoking during pregnancy vs smoking	1170	0.9	0.0, 1.7	0.045	1057	0.7	-0.3, 1.8	0.185
Maternal age at birth (years)	3715	-0.0	-0.5, 0.4	0.839	3434	-0.2	-0.7, 0.4	0.531
Maternal brisk walking (never as baseline)	820				767			
<1 hr/week	997	0.4	-1.0, 1.7		962	0.5	-1.0, 1.9	
≥2 hrs/week	1585	1.1	-0.1, 2.4	0.141[b]	1517	1.2	-0.1, 2.4	0.163[b]
Maternal swimming (never as baseline)	1862				1757			
< 1hr/week	1184	1.6	0.5, 2.6		1147	1.9	0.9, 3.0	
≥2 hrs/week	339	2.6	0.9, 4.3	<0.001[b]	332	2.8	1.1, 4.5	<0.001[b]

Table 8.50 Associations between prenatal exposures and MVPA in children aged 11 to 12 years

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
Parity (0 as baseline)	1681				1577			
1	1263	1.3	0.3, 2.3		1185	1.3	0.2, 2.3	
2 +	664	3.3	1.9, 4.7	<0.001[b]	604	3.0	1.5, 4.5	<0.001[b]
Season of birth[c] (Spring as baseline)	915				851			
Summer	1103	1.0	-0.5, 2.3		1031	0.9	-0.7, 2.5	
Autumn	992	-0.9	-2.4, 0.8		901	-0.9	-2.6, 0.9	
Winter	705	1.2	-0.4, 2.8	0.638	651	1.2	-0.5, 2.9	0.622

Model 1 adjusted for age and gender. Model 2 adjusted for age, gender, parental social class by occupation and mother's education.
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable (SD=3.9)
[b] P for linear trend
[c]Winter= December, January, February; Spring= March, April, May; Summer= June, July, August; Autumn= September, October, November. Additionally adjusted for season of measurement.

Table 8.51 Associations between early childhood exposures (0-2 years) and MVPA in children aged 11 to 12 years

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
Activity at 6 months[ab]	3314	-0.0	-0.5, 0.4	0.878	3126	-0.2	-0.7, 0.3	0.533
Motor coordination at 6 months[ac]	3418	0.7	0.2, 1.2	0.009	3215	0.8	0.2, 1.3	0.009
Partner at 8 months? Yes vs	3363				3186			
no	107	2.0	-0.9, 4.8	0.172	81	2.7	-0.8, 6.1	0.129
Parents activity at 21 months. Neither active as baseline	688				646			
Either active	1422	2.0	0.7, 3.2		1364	1.8	0.5, 3.1	
Both active	620	2.9	1.3, 4.5	<0.001[d]	592	2.7	1.0, 4.3	0.004[d]
Time outside at 24 months (<7 hrs/wk as baseline)	747				685			
7-13 hrs/wk	944	-1.5	-2.9, -0.1		897	-1.4	-2.8, 0.1	
>13 hrs/wk	1684	-0.5	-1.7, 0.8	0.061	1591	-0.3	-1.7, 1.0	0.105
Breast feeding 6 months (still breastfeeding as	1242				1195			

Table 8.51 Associations between early childhood exposures (0-2 years) and MVPA in children aged 11 to 12 years, contd

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
baseline)								
Yes, stopped	1636	-0.5	-1.6, 0.5		1520	-0.7	-1.8, 0.4	
Never	615	-1.2	-2.5, 0.2	0.251[d]	570	-1.5	-3.0, 0.0	0.143[d]

Model 1 adjusted for age and gender. Model 2 adjusted for age, gender, parental social class by occupation and mother's education.
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable [b]SD=6.3; [c]SD=5.2
[d]P for linear trend

Table 8.52 Associations between pre-school exposures (2-5 years) and MVPA in children aged 11 to 12 years

	Model 1				Model 2			
Exposure	N	Regression coefficient	95% CI	P	N	Regression coefficient	95% CI	P
Time outside at 38 months (<7 hrs as baseline)	1373				1298			
7-13 hrs/wk	777	0.9	-0.4, 2.3		737	0.9	-0.5, 2.3	
>13 hrs/wk	1158	0.3	-0.8, 1.4	0.403[d]	1078	0.4	-0.7, 1.6	0.445[d]
Time outside at 54 months (<14 hours/week as baseline)	687				649			
14-20 hours/week	1084	0.3	-1.7, 1.0		1019	-0.3	-1.7, 1.1	
>20 hours/week	1441	0.3	-1.0, 1.6	0.518[d]	1362	0.3	-1.1, 1.7	0.590[d]
TV viewing at 38 months (<10, >10hours/week)	2544				2403			
	773	-0.9	-2.1, 0.3	0.137	719	-1.0	-2.3, 0.2	0.099
TV viewing at 54 months (<10, >10 hours/week)	1008				949			
	2219	-0.7	-1.8, 0.3	0.169	2094	-0.9	-2.0, 0.3	0.131
Sleep at 30 months (hours/night)[a]	3322	0.2	-0.3, 0.7	0.341	3118	-0.0	-0.6, 0.5	0.951

Model 1 adjusted for age and gender. Model 2 adjusted for age, gender, parental social class by occupation and mother's education
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable; SD=0.96. [b]P for linear trend

Tables 8.53 to 8.56 show Model 3 for MVPA. Model 3 is adjusted for age and gender but restricted to those who were in Model 2. The results were similar to that of Model 1.

Table 8.53 Associations between birth outcomes and MVPA in children aged 11 to 12 years

	Model 3			
Exposure	N	Regression coefficient[a]	95% CI	P
Birthweight (100g)[b]	4671	0.1	-0.4, 0.6	0.706
Ponderal index (Kg/m3)[c]	3738	-0.1	-0.5, 0.3	0.658
Head circumference (cm)[d]	3834	0.0	-0.5, 0.5	0.976
Crown-heel length (cm)[e]	3786	0.1	-0.4, 0.6	0.574
Gestation (weeks)[f]	4739	-0.1	-0.5, 0.4	0.738

Model 3 adjusted for age and gender, restricted to those in Model 2.
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable. [b]SD=5.1; [c]SD=3.0; [d]SD=1.5; [e]SD=2.4; [f]SD=1.7

Table 8.54 Associations between prenatal exposures and MVPA in children aged 11 to 12 years

		Model 3		
Exposure	N	Regression coefficient	95% CI	P
Maternal BMI (Kg/m^2)[a]	4394	-0.6	-1.1, -0.2	0.005
Maternal non-smoking vs	3757			
smoking	664	1.4	0.2, 2.6	0.022
Partner non-smoking	3200			
during pregnancy vs smoking	1456	0.8	-0.1, 1.7	0.068
Maternal age at birth (years)	4739	-0.2	-0.6, 0.2	0.305
Maternal brisk walking (never as baseline)[a]	1041			
<1 hr/week	1339	0.6	-0.6, 1.8	
≥2 hrs/week	2103	1.5	0.4, 2.6	0.015[b]
Maternal swimming (never as baseline)	2399			
< 1hr/week	1589	1.6	0.7, 2.6	
≥2 hrs/week	485	1.6	0.2, 3.0	<0.001[b]
Parity (0 as baseline)	2183			
1	1637	1.0	0.1, 1.9	
2 +	828	2.5	1.3, 3.7	<0.001[b]

Table 8.54 Associations between prenatal exposures and MVPA in children aged 11 to 12 years, contd

	Model 3			
Exposure	N	Regression coefficient	95% CI	P
Season of birth[c] (Spring as baseline)	1089			
Summer	1420	0.8	-0.3, 1.9	
Autumn	1337	0.2	-0.9, 1.4	
Winter	893	1.0	-0.2, 2.	0.271

Model 3 adjusted for age and gender, restricted to those in Model 2.
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable (BMI SD=3.7; maternal age SD=4.4)
[b]P for linear trend
[c]Winter= December, January, February; Spring= March, April, May; Summer= June, July, August; Autumn= September, October, November. Additionally adjusted for season of measurement.

Table 8.55 Associations between early childhood exposures (0-2 years) and MVPA in children aged 11 to 12 years

	Model 3			
Exposure	N	Regression coefficient	95% CI	P
Activity at 6 months[ab]	4303	-0.1	-0.5, 0.3	0.633
Motor coordination at 6 months[ac]	4452	0.5	0.0, 1.0	0.036
Partner at 8 months? Yes vs no	4422			
	103	1.3	-1.5, 4.1	0.364
Parents activity at 21 months. Neither active as baseline	866			
Either active	1876	2.3	1.2, 3.4	
Both active	844	3.2	1.8, 4.6	<0.001[d]
Time outside at 24 months (<7 hrs/wk as baseline)	946			
7-13 hrs/wk	1224	0.9	-2.1, 0.3	
>13 hrs/wk	2211	-0.2	-1.3, 0.9	0.217[d]
Breast feeding 6 months (still breastfeeding as baseline)	1629			
Yes, stopped	2157	-0.4	-1.3, 0.6	
Never	749	-0.9	-2.2, 0.3	0.344[d]

Model 3 adjusted for age and gender, restricted to those in Model 2.
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable [b]SD=6.2; [c]SD=5.1
[d]P for linear trend

Table 8.56 Associations between pre-school exposures (2-5 years) and MVPA in children aged 11 to 12 years

	Model 3			
Exposure	N	Regression coefficient	95% CI	P
Time outside at 38 months (<7 hrs as baseline)	1810			
7-13 hrs/wk	1043	0.4	-0.7, 1.5	
>13 hrs/wk	1464	0.4	-0.6, 1.4	0.653[b]
Time outside at 54 months (<14 hours/week as baseline)	894			
14-20 hours/week	1439	-0.1	-1.3, 1.1	
>20 hours/week	1849	0.2	-1.0, 1.4	0.867[b]
TV viewing at 38 months (<10,	3367			
>10hours/week)	967	-0.5	-1.6, 0.5	0.331
TV viewing at 54 months (<10,	1354			
>10 hours/week)	2853	-0.4	-1.3, 0.5	0.422
Sleep at 30 months (hours/night)[a]	4310	0.2	-0.2, 0.6	0.399

Model 3 adjusted for age and gender, restricted to those in Model 2.
[a]Standardised regression coefficient - change in counts per minute per SD of exposure variable; SD=0.95. [b]P for linear trend

8.6.11 Summary

- No birth outcomes were associated with later physical activity

- Of the prenatal variables, maternal physical activity during pregnancy, maternal and partner's smoking and season of birth showed modest associations with later physical activity

- Parental activity at 21 months and TV viewing at 38 and 54 months showed small associations with later physical activity

- Overall, few exposures in the first five years old children's lives showed any association with physical activity at ages 11 to 12. For those that did the associations tended to be small

Chapter 9. Discussion

The Discussion section is divided into two chapters. Chapter 9 discusses the results from each of the papers listed below. Chapter 10 is broader and will bring together the issues addressed separately in Chapter 9 and examine the implications for physical activity research in children and the implications for policy. As with previous chapters, Chapter 9 comprises five sections based on the following papers

- Mattocks C, Ness A, Leary S, Tilling K, Blair SN, Shield J, Deere K, Saunders J, Kirkby J, Davey Smith G *et al.*: Use of accelerometers in a large field based study of children: protocols, design issues and effects on precision. Journal of Physical Activity and Health. 5 (Supp 1): S98-S111, 2008 [1]

- Mattocks C, Ness A, Leary S, Tilling K, Deere K, Kirkby J, Saunders J, Riddoch C and Blair S: Calibration of an accelerometer during free-living activities in children. International Journal of Pediatric Obesity. DOI: 10.1080/17477160701408809, 2007 [2]

- Mattocks C, Leary S, Ness A, Deere K, Saunders J, Kirkby J, Blair S, Tilling K and Riddoch C: Intra-individual variation of objectively measured physical activity in children. Medicine & Science in Sport and Exercise. 39: 622-629, 2007 [3]

- Riddoch C, Mattocks C, Deere K, Saunders J, Kirkby J, Tilling K, Leary S, Blair S and Ness A: Objective measurement of levels and patterns of physical activity. Archives of Disease in Childhood. DOI: 10.1136/adc.2006.112136, 2007 [4]

- Mattocks C, Ness A, Deere K, Tilling K, Leary S, Blair SN and Riddoch C: Early life determinants of physical activity in 11-12 year olds: a cohort study. British Medical Journal. DOI: 10.1136/bmj.39385.443565.BE, 2007 [5]

Copies of these papers are in Appendices 1 to 5.

9.1 Use of accelerometers in a large field based study of children: protocols, design issues and effects on precision

The aims of this study were to develop methods and protocols to incorporate accelerometer measurements of physical activity into an existing longitudinal study and to examine the number of days and hours per day needed to give good reliability and an adequate sample size.

This section will discuss the following:

- Main findings of the study
- Comparison with other studies
- Strengths of the study
- Limitations of the study
- Summary

This analysis is known informally as the Methods study. The methods and results are in Chapter 6 (Section 6.2), Chapter 7 (Section 7.2.1) and Chapter 8 (Section 8.1), respectively.

9.1.2 Main findings of the study

9.1.2.1 Compliance with the study protocol

Seventy eight per cent of children who attended the 11-year clinic provided valid data (see Figure 8.1). This is consistent with results from two previous studies. Riddoch *et al.* measured physical activity in 9 and 15 year old children in four European countries. Using similar procedures to this study to exclude non-valid data, 75% of children who took part in the study had valid data for at least 3 days for at least 10 hours per day [62]. In a feasibility study of accelerometry in children from grades 6-8, Van Coevering et al. found that 234 of 282 children (83%) provided three valid days of recording [176].

9.1.2.2 Number of days of measurement and start day

The use of three days of physical activity measurement gave good reliability (R=0.7; Table 8.2). It has been suggested that a minimum of four days of measurement is required to give a reliability coefficient of 0.8 [177]. However, a reliability coefficient of 0.7 maximises power by increasing the sample size and reduces the number of participants excluded for future analyses (see Table 8.3). The small difference in counts per minute between weekdays and weekend days and similar power suggests that including a weekend is not necessary in this sample though this may not be the case for smaller studies. Similar single-day ICCs for different minimum acceptable day lengths gave similar estimates for the number of days required to achieve pre-specified reliabilities (see Table 8.2). Despite this, 600 minutes was chosen as the minimum day length as it a) minimises the possible effects of varying day length on physical activity outcomes and b) allows comparison with other studies. Use of the Spearman-Brown formula does have some limitations as it relies on compound symmetry i.e., that the variances for each day are equal and correlations between pairs of days are equal [178]. Correlations for counts per minute between pairs of days in this study ranged from 0.39 to 0.48 in the data so this is unlikely to constitute a problem.

Children with fewer days of recording tended to have higher total physical activity (counts per minute) but these differences were modest - the biggest difference (40 counts per minute or about 0.2 SDs) was between 3 days of measurement (the minimum) and 7 days of measurement (the maximum). There were differences in total counts per minute depending on the start day. Children who started on a Monday had the lowest counts per minute and children who started on a Wednesday had the highest counts per minute. Saturday was the most popular day to attend the clinic and counts per minute was also lower than average when children started on this day. This is difficult to explain and may represent a chance finding though it may be that children with a Monday start day were a different group from the rest since there was no clinic on Sundays and a Monday start day had to be specifically requested. There was also a difference in activity depending on whether children started on a weekday or weekend day although the difference was small (17 counts per minute or about 0.1 SDs).

9.1.2.3 Instrument reactivity

Reactivity (the tendency of the instrument to modify normal behaviour) has been highlighted as a potential problem in the measurement of physical activity [38]. Although a difference in total activity between the first day and the mean of all subsequent days was found, this was small at 17 counts per minute (about 0.1 SDs) and it is unlikely that this would overestimate physical activity levels. (This is coincidentally the same difference as that between a weekday and weekend day start).

9.1.3 Differences between participants and non-responders

There were small differences between children with and without valid Actigraph data. Boys were less likely to provide valid data and children with valid data had lower BMI, although the difference was small. This is in contrast to Van Coevering *et al.* who found that overweight children were more likely to provide 7 days of complete data [176]. Children with valid data tended to be younger and lighter and more children with valid data were in later stages of pubertal development compared to those who did not provide valid data, but again these differences were small. There were also some differences in terms of maternal education - a marker of socio-economic position. Those who provided valid data tended to have mothers with higher educational levels (i.e., higher socioeconomic position). However, the difference was small and unlikely to introduce bias as the association between socio-economic position and physical activity in children in this population is weak and inverse (i.e., lower socio-economic position is associated with slightly higher total physical activity) [179]. These results suggest subject characteristics that might be targeted to maximise compliance.

9.1.4 Strengths of the study

The major strength of this study is the use of an objective measure of physical activity. This allows for a more precise and accurate measure of physical activity (see Chapter 3), which should enable the detection of associations that cruder instruments, such as, self-report, may miss. The output from the accelerometer is also continuous and this allows for more flexibility in the analyses i.e., analyses using total physical activity or categorisation of activity e.g., using quintiles of physical activity to look for dose response relationships [96]. The clock within the Actigraph also allows minutes of MVPA to be estimated and for daily patterns of physical activity to be described.

9.1.5 Limitations of the study

Due to the large volume of data collected, it was not possible to examine each Actigraph file individually to check for errors. This may have resulted in spurious patterns of data being accepted as valid. However, the stringent exclusion criteria for dealing with outliers during the data cleaning kept implausible data to a minimum. Most studies, including this one, use a one-minute measurement epoch. There has been considerable debate on the most appropriate epoch length to use [38]. The concern is that using a one-minute epoch may "mask" the short bursts of vigorous activity that are typical in children [32] by averaging them over one minute. Nilsson *et al.*[180] found that vigorous and very vigorous activity was underestimated when a one-minute epoch was compared with a 5 second epoch. This may result in misclassification of children in these categories of intensity though comparison with this study is difficult as Nilsson *et al.* used different cut-points and classifications for intensity levels [180]. However, this would not affect the main outcome measure of this study, which was volume of physical activity assessed by counts per minute.

The results of this study will be informative for other researchers when deciding on study methodology, so it is important to recognise that this analyses and the decisions made may not be appropriate for all studies. For example, the relatively large sample maximised power and gave reasonable reliability with three days of recording. The use of three days is less than has previously been recommended [177] although other large studies have used three days [62]. Studies with smaller sample sizes may wish to measure a greater number of days and to process data by hand to improve measurement precision.

9.1.6 Summary

- These results provide an overview of the accelerometry processing and compliance patterns in a large study of children
- Three days of measurement resulted in good reliability and power
- Systematic differences in counts per minute between numbers of days of measurement were small
- The differences in the characteristics of the children who completed the protocol and those that didn't were modest
- There was some potential for a small amount of bias depending on which day of the week children started wearing the Actigraph

9.2 Calibration of an accelerometer during free-living activities in children

The aims of this study were to develop an equation to predict energy expenditure from Actigraph counts and to derive cut-points for moderate and vigorous physical activity.

This section will discuss the following:

- Main findings of the study
- Comparison with other studies
- Strengths of the study
- Limitations of the study
- Summary

This analysis is known informally as the K4 study. The methods and results are in Chapter 6 (Section 6.3.2), Chapter 7 (Section 7.2.2) and Chapter 8 (Section 8.2), respectively.

9.2.1 Main findings of the study

In this calibration study it was found that Actigraph counts, adjusted for age and gender could predict energy expenditure across a range of activities. By refitting the model with VO_2 instead of energy expenditure as the outcome, cut-points for moderate and vigorous activity were derived.

This is the first validity study of the Actigraph that has derived an energy expenditure equation and developed cut-points specifically in children of this age. The use of self-paced, "free-living" activities may reflect better than laboratory-based studies the ways in which children perform activities in the real world. This may to some extent account for differences in fitness between individuals.

9.2.2 Comparison with other studies

Several studies have developed prediction equations or defined cut-points for activity intensity thresholds in children, though study populations, sample sizes and study protocols have varied. Reported R^2 values of 75% [181], 61% [55], 83% [65], 50% (for physical activity energy expenditure i.e., energy expenditure during activity- resting energy expenditure [39]) and a model concordance correlation coefficient of 85% [182] are similar to this study (R^2 67.3%). The inclusion of age and gender made only modest contributions to the overall R^2 in the model. Table 9.1 compares energy expenditure prediction equations for an "average" child from this study working at the mean Actigraph counts per minute for moderate physical activity in this study of 4175 counts per minute. As can be seen, there is a wide range in energy expenditure predicted for this child (ranging from 0.346 to 0.562 $kJ \cdot kg^{-1} \cdot min^{-1}$). Some studies have included weight [65,182] and age [181] as covariates in their equations. Differences in study populations and also in study design, including type of activities undertaken, may have contributed to the differences in energy expenditure predicted from previous equations.

Table 9.1 Comparison of energy expenditure prediction equations from previous studies

Authors	Population	Study design	Prediction equation	Moderate activity energy expenditure[a] ($kJ \cdot kg^{-1} \cdot min^{-1}$)
Trost *et al.* [65]	30 children aged 10-14	Laboratory-based. Oxygen uptake as criterion measure. 3 activities	EE ($kcal \cdot min^{-1}$) = -2.23 + 0.0008cpm + 0.08 weight (kg)	0.444
Puyau *et al.* [181]	26 children aged 6-16	Laboratory and field-based. Oxygen uptake as criterion measure. 9 activities	EE ($kcal \cdot kg^{-1} \cdot min^{-1}$)= 0.0654- 0.00197age+ 0.00001cpm[b]	0.346
Schmitz *et al.* [182]	74 girls aged 13-14	Field-based Oxygen uptake as criterion measure. 10 activities	EE ($kJ \cdot min^{-1}$) = 7.6628 + 0.1462 [(cpm- 3000)/100] + 0.2371weight (kg) - 0.00216 $[(cpm - 3000)/100]^2$ +0.004077[((cpm- 3000)/100)weight (kg)]	0.500
Current study	246 children aged 12	Field-based. Oxygen uptake as criterion measure. 4 activities	EE ($kJ \cdot min^{-1} \cdot kg^{-1}$)= -0.933 + 0.000098 cpm + 0.091 age (years) -0.0422 gender (male=0, female=1)	0.562

EE= energy expenditure, cpm= counts per minute
[a]Based on "average" girl from the current study. Aged 12.4 years, BMI 18.9, Height 150.6cm, weight 42.3kg, accelerometer counts per minute 4175. Values converted to $kJ \cdot min^{-1} \cdot kg^{-1}$
[b]This equation is different from the original published equation. An erratum has been published [183]

Current guidelines recommend that children do at least 60 minutes of moderate to vigorous physical activity (MVPA) per day [121]. Interpretation of Actigraph data to assess whether guidelines are being met relies on accurately placed cut-points. Several groups have conducted studies to estimate cut-points for sedentary, light, moderate or vigorous physical activity in children. These are summarised in Table 9.2 for comparison with the present study.

Table 9.2 Activity intensity thresholds of previous studies compared with this study

Authors	Population	Epoch time		Criterion for intensity	Activity intensity	Threshold counts
Puyau *et al.* [181]	26 children aged 6- 16	1 minute		<0.015[b]	sedentary	0-800
				≥0.015	light	801-3200
				<0.05	moderate	3201-8200
				≥0.10	vigorous	>8200
Trost *et al.*[a] [184]	80 children aged 6-18	1 minute		≥3 METs	moderate	>1267
				≥6 METs	vigorous	≥4057
Reilly[c] *et al.* [68]	82 children aged 3-4	1 minute		*a priori* categorisation	sedentary	<1100
Treuth *et al.* [162]	74 girls aged 13-15	30s		*a priori* categorisation	sedentary	0-100
					light	101-2999
					moderate	3000-5200
					vigorous	>5200
Sirard[c] *et al.* [185]	3 groups of children aged 3, 4 and 5	15s	Age 3 n = 74	*a priori* categorisation	sedentary	0-1204
					light	1205-2456
					moderate	2457-4920
					vigorous	>4920
			Age 4 n = 130	*a priori* categorisation	sedentary	0-1452
					light	1453-3244
					moderate	3245-4936
					vigorous	>4936
			Age 5 n = 81	*a priori* categorisation	sedentary	0-1592
					light	1593-3560
					moderate	3561-5016
					vigorous	>5016
Current study	246 children aged 12	1 minute		≥3 METs	moderate	2306
				≥4 METs	moderate	3581
				≥6 METs	vigorous	6130

Threshold counts reported as counts per minute for comparison and rounded where appropriate
[a]Based on the mean age of the current study
[b]$kcal \cdot kg \cdot min^{-1}$
All studies used oxygen uptake as the criterion measure except[c] which were based on direct observation

The cut point for MVPA is higher than the commonly used Trost *et al.* [184] cut-point, although recent studies have suggested that a higher cut-point may be more appropriate (see Table 9.2). In previously conducted validity studies, energy expenditure prediction equations and cut-points have varied (see Tables 9.1 and 9.2) [186], raising the possibility of inaccurate estimates of energy expenditure or misclassification into categories of physical activity intensity e.g., MVPA.
Four of the studies in Table 9.2 [162,181,184] used VO_2 as the criterion for deriving cut-points. Two [68,185] used direct observation as the criterion measure. Previous studies have categorised activity intensity in different ways. Puyau *et al.* used energy expenditure ($kcal \cdot kg \cdot min^{-1}$) [181]; Trost *et al.* used energy expenditure (METs) [184] whereas Treuth *et al.* [162], Sirard *et al.* [185] and Reilly *et al.* [68] categorised activities *a priori* e.g., brisk walking (3.5mph) was defined as moderate [162]. Differences in defining categories of physical activity intensity, sample-size, study protocol and characteristics of the study population may account for the differences in cut-points seen. Changes in body composition, stride pattern, oxygen uptake kinetics and efficiency of movement as children mature make it unlikely that one set of cut-points or prediction equation will be generalisable for all ages. A "suite" of equations, each suitable for a particular age group may be the most appropriate way to address these issues of maturation and development in children.

An alternative method of accounting for differences in body size and movement efficiency is to use the activity-related time equivalent based on accelerometry (Arte*ACC*) which is calculated as Arte*ACC* = total daily activity counts/reference exercise counts per minute [187]. However, Ekelund *et al.* suggest that high interindividual variability observed during treadmill walking (the reference exercise), indicated the need for individual calibration [187]. This may preclude the use of this index in large studies.

9.2.3 Strengths of the study

The main strength of this study is the sample size that was large enough to allow for adjustment for confounders. Further, the use of self-paced, "free-living" activities may better reflect the way in which children perform activities in the real world and may to some extent account for differences in fitness between individuals. This is one of the few calibration studies of the Actigraph to have used mixed model regression analysis. Welk recommends using such models in order to account for the non-independence of multiple data points for individuals [186].

9.2.4 Limitations of the study

Practical considerations prevented inclusion of more activities in this study. It could be argued that the use of largely locomotor activities do not wholly reflect the activities of daily living that children do. For example, no activities that required mainly arm movements were included. However, Sleap and Warburton found that children's activities largely consisted of locomotor activities such as soccer and brisk walking [166]. In adults, equations derived to predict energy expenditure from walking activities perform less well when applied to common household activities that require a lot of upper body movement [188]. Activities in this study were performed on a level track whereas children's activity in the real world would include walking or running on inclines where the Actigraph is known to perform less well [39]. The activities performed by the children may represent the type of movement that the Actigraph measures better than other activities such as climbing. The Actigraph has been reported to underestimate energy expenditure at high running speeds in adults [189] and activities that involved high running speeds were not included in this study. This may result in time spent in vigorous activity being underestimated by the equation in this study. Though time spent in vigorous activity may only represent a small proportion of total activity time, it may represent a higher proportion of total activity. Baquet *et al.* reported that pre-pubertal children spend 2.4% of their time in vigorous and very high intensity physical activity but that this accounted for 36.1% of their total physical activity [61].

This study did not attempt to define a threshold for sedentary behaviour. It has been argued that sedentary behaviour constitutes a health behaviour that is independent of physical activity [190]. Although other studies have defined cut-points for sedentary behaviour in children and adolescents of different ages, these have varied considerably by age [68,162]. More studies need to be carried out to define sedentary behaviour across a range of ages in order to better examine the health consequences of sedentary behaviour in children.

The mean difference and limits of agreement between actual and estimated energy expenditure (-0.01 $kJ \cdot kg \cdot min^{-1}$; -0.28, 0.25) suggest that the prediction equation may be imprecise when used on an individual level rather than at group level. This is line with other studies, for example Reilly *et al.* report that energy expenditure prediction equations may only be suitable for use at group level [191].

The VO_2 values used for resting energy expenditure were not collected using a standard protocol. The measurement period was five minutes whereas a 15-minute protocol is commonly used [165]. However, the mean resting VO_2 was 5.7 $mL \cdot kg^{-1} \cdot min^{-1}$ in the developmental group which is similar, although slightly higher, to that reported for children of a similar age in the study of Harrell *et al.* [165]. In this study, boys aged 8 to 12 years and girls aged 8 to11 years comprised one group (n= 129) with a mean resting VO_2 of 5.92 $mL \cdot kg^{-1} \cdot min^{-1}$. A second group (n= 83) comprised boys aged 13 to 15 years and girls aged 12 to14 years with a mean resting VO_2 of 4.58 $mL \cdot kg^{-1} \cdot min^{-1}$ [165]. Although the age groups are not identical to that of the K4 study of 12.4 years, the values from Harrell *et al.* suggest that the resting VO_2 estimated by this study may be slightly high. Another study reported that resting VO_2 was 4.5 $mL \cdot kg^{-1} \cdot min^{-1}$ in circumpubertal children (boys aged 12.6 to 14.2 years; n= 15 and girls aged 11.1 to12.9 years; n= 15) [192]. If the resting VO_2 in the current study is higher than would be expected in children of this age, then this would have the obvious effect of setting the cut-point for MVPA too high which in turn would underestimate the amount of MVPA undertaken. There are, however, other variables that can affect the derivation of cut-points. These include the choice of MET cut-point, which the Actigraph cut-points are derived from. These are often arbitrarily chosen and may not always be appropriate for children. Guinhouya and Hubert point out that a three MET threshold is often used but that this may be too low for children and that between four and six METs may be more appropriate [193].

The final minute of each five-minute activity was used in order to allow VO_2 to stabilise after the previous activity so that the VO_2 accurately reflected the energy expenditure of each activity. Children's activities are often not sustained and it may therefore be that steady state values such as these apply less well in free-living children.

9.2.5 Summary

- Equations for predicting energy expenditure from accelerometer counts vary considerably between studies

- Intensity cut-points for moderate and vigorous activity that were higher than those previously used were also derived

- This study demonstrated that reasonable estimations of energy expenditure can be made utilising accelerometer data together with other easy to measure variables

- Estimations of energy expenditure are suitable for use at group level and not in individuals due to the error in such estimates

- Cut-points for moderate and vigorous activity were also defined that will be of use in studies of children from a similar age group

9.3 Intra-individual variation of objectively measured physical activity in children

9.3.1 Objectives

The aim of this study was to estimate the variability of children's physical activity over one year by taking repeat measures and by using the ICC to estimate the variability.

This section will discuss the following:

- Main findings of the study
- Comparison with other studies
- Strengths of the study
- Limitations of the study
- Summary

This analysis is known informally as the Four Seasons study. The methods and results are in Chapter 6 (Section 6.3.3) and Chapter 7 (Section 7.2.3), Chapter 8 (Section 8.3), respectively.

9.3.2 Main findings of the study

9.3.2.1 Intraclass correlation coefficients

The ICC for counts per minute, adjusted for gender, age, BMI and month was 0.53, suggesting that there is substantial intra-individual variation in children's physical activity- an ICC of 1.0 would indicate that all the variation is between rather than within children. The small amount of attenuation from 0.54 to 0.49 after adjustment for gender, age and BMI suggests that these estimates were not markedly affected by these confounding factors. The increase in ICC from 0.49 to 0.53 after adjustment for month of measurement indicates a similarly small effect of month of measurement.

The analysis was repeated under the following conditions: pubertal status at baseline included as a covariate; children who reported any swimming or cycling excluded; children who wore the monitor during school holidays excluded; or restricting to those who had data for all four measurement occasions. For all these analyses, the ICCs remained unchanged. This suggests that the estimated ICCs of these children's activity was unaffected by the modest amount of swimming and cycling done, whether the children were at school or on holiday or whether they had complete data for all measurement occasions. The ICC for counts per minute for weekdays only was similar to that for the whole measurement period at 0.51 but was lower for weekends only at 0.39, suggesting that there was more intra-individual variation at the weekend. The ICCs for minutes of MVPA, minutes of vigorous physical activity and blocks of sedentary behaviour of at least 30 minutes all show more intra-individual variation. All ICCs remained unchanged or were similar after adjustment for gender, age, BMI and month. The inclusion of two sine and two cosine functions for MVPA seasonality suggests two peaks and two troughs in the data as indicated in Figure 8.1.

The size of the ICCs (ranging from 0.37 to 0.59 for combined analyses) indicates that there is substantial instability in children's physical activity over one year. The study design allowed us to estimate the ICC- a measure of reliability that can be used to correct for regression dilution which may occur when an exposure is imprecisely measured i.e. when a single measure is used to estimate the "usual" value of a parameter which may vary over time [194]. This can result in under-estimation of the regression co-efficient where, for example, physical activity is the exposure and obesity is the outcome. The regression coefficient can be corrected by dividing by the ICC. As the ICC in this study is 0.53, this would effectively double the regression co-efficient for the relationship between the outcome and physical activity (the exposure). However, this assumes that all the variation is intra-individual variation, which may not be the case. Where physical activity is the outcome, measurement error in physical activity will not cause bias, but will result in a large residual error (i.e. a large amount of the variation in the outcome being unexplained by the regression equation). This will result in coefficients being estimated with larger standard errors, and thus wider confidence intervals and larger P values.

9.3.2.2 Seasonal associations

Although not an *a priori* hypothesis, counts per minute for summer and winter was 615 and 522 counts per minute, respectively. Studies have demonstrated seasonal differences in physical activity similar to the observations reported here. Fisher *et al.* found that in the UK, total activity measured by accelerometry was highest in the summer months (May, June, July) among 209 three to five year olds [154]. Similar seasonal differences have also been reported using doubly-labeled water to assess physical activity level cross-sectionally in children [195] and longitudinally in young adults [196]. In both studies, physical activity levels were higher in the summer than in the winter [196]. Seasonal differences in physical activity may be due to differences in climatic conditions such as temperature rather than the seasons, per se. Baranowski *et al.* also found seasonal differences in the physical activity of 191 three to four years olds in Galveston, Texas using direct observation, with children tending to be less active when outside during the summer months and more active during the winter months [197]. This contradictory finding may be due to the differences in temperature and humidity between the southern US and the UK. For example, Fisher et al. reported mean summer and winter temperatures during their study period in Glasgow of 12.8 °C and 6.4 °C, respectively [154]. During our study, seasonal temperature averages for the geographical region were 15.5 °C during summer and 5.4 °C during winter. The average temperature in Galveston, Texas during summer was approximately 28 °C and 14 °C in winter [197].

9.3.3 Comparison with other studies

Several studies have estimated the variability over single measurement occasions. Treuth *et al.* found an ICC of 0.37 in 68 girls aged 8-9 for counts per minute over a 4-day measurement period [198]. In 30 children aged 7-15, Janz *et al.* observed ICCs for counts per minute ranging from 0.75-0.78 and 0.81-0.84 for 4 and 6 days of monitoring, respectively [199]. For minutes of MVPA, an ICC of 0.42 for one day of measurement was reported by Murray *et al.* [200]. Trost *et al.* studying children and adolescents, found ICCs for minutes of MVPA of between 0.64-0.79 and 0.76-0.86 (depending on age group) for 4 and 7 days of measurement respectively [177]. With the exception of Treuth *et al.* [198] studies that use single measurements generally have higher ICCs than those found in this study, 0.53 for counts per minute and 0.45 for minutes of MVPA. This could be due to differences in study population. For example, Trost et al. found that the ICC for MVPA was lower (i.e. intra-individual variation was greater) in older children [177]. It could also be affected by whether the children were assessed during term-time or while on holiday from school. Or, it could represent genuine intra-individual variability that occurs over longer periods as it is known that children's physical activity levels decrease as they get older [201]. Differences in MVPA cut-points could also account for the relatively low ICC. Trost *et al.* [177] used a cut-point that was about half (depending on age-group) [202] that of our cut-point of 3600 counts per minute. A lower cut-point allows a greater range of potential values from which to calculate the ICC, which in turn, can increase the magnitude of the ICC [203]. Examination of different numbers of days of measurement showed that increasing the number of days increased the reliability. This is not surprising and is consistent with other studies that have reported an increase in reliability with an increase in the number of days of measurement [177,199]. There was still substantial variability across a year, even in children with six to seven days of valid measurement.

There are few studies that have used a repeated-measures design and an objective measure to estimate the variability of physical activity. Levin *et al.* measured physical activity in 77 adults using the Caltrac accelerometer worn for 48 hours every 26 days for a year. The ICC was 0.42, indicating considerable intra-individual variation over a one year period and they observed seasonal differences with more physical activity recorded in the summer months compared to winter [174]. The ICC for total activity in this study at 0.53 is higher, indicating more stability although the difference is small. This may be due to the lower number of days on each measurement occasion in the Levin *et al.* study - two days vs. three to seven days in this study.

9.3.4 Strengths of the study

This is the first study that has used a repeat measures design with an objective method of measuring physical activity in children to assess the intra-individual variation of the course of a year. The use of the Actigraph allows for more accurate and precise measurement and avoids the possibility of recall bias that self-report instruments may have. The repeat measures nature of this study also allowed for seasonality of physical activity to be assessed longitudinally rather than using a cross-sectional design such as has been used in other studies [154].

9.3.5 Limitations of the study

Although the main outcome in this study was total activity in counts per minute, the variability of MVPA was also estimated. This study used one-minute epochs, which are generally used in field studies, as this allows approximately 22 days of recording. Studies of direct observation have shown that 95% of children's physical activity bouts last less than 15 seconds [32]. The use of one-minute epochs may therefore have the effect of "diluting" the amount of MVPA and vigorous activity, which may have led to an underestimation in the amount of recorded MVPA. It has been suggested that shorter epochs should be used in order to capture moderate and vigorous activity [177,180]. Some of the variation in sedentary behaviour may have been due to the variation in the number of hours per day the monitor was worn. A valid day was a minimum of 10 hours although monitors were worn for an average of 13.1 hours per day therefore it is likely that the variation in sedentary behaviour due to day length will be minimal.

The children in this study will have matured over the course of the study period and will have matured at different rates [204]. It may be that the development and increasing age of children in the current study has an effect on their physical activity [154]. This issue was addressed by controlling for pubertal status at baseline. However, it was not possible to control for changes in pubertal status over the study period or changes in height or weight so the impact of any changes on ICC estimates remain unknown.

9.3.6 Summary

- Children's physical activity showed considerable intra-individual variation and seasonal variation when measured four times over a one-year period

- A single measurement occasion may not adequately characterise usual children's physical activity.

- The estimated ICCs presented here can be used to correct for regression dilution in order to obtain more accurate effect size estimates.

9.4 Objective measurement of levels and patterns of physical activity

9.4.1 Objectives

This aim of this study was to estimate levels and patterns of children's physical activity at age 11 years and to examine the associations between physical activity and socioeconomic status, season of the year and pubertal status.

This section will discuss the following:

- Main findings of the study
- Strengths of the study
- Limitations of the study
- Summary

This analysis is known informally as the Descriptives study. The methods and results are in Chapter 6 (Section 6.2), Chapter 7 (Section 7.2.4) and Chapter 8 (Section 8.4), respectively.

9.4.2 Main findings of the study

9.4.2.1 Total physical activity

In keeping with previous studies, [62,184,205] boys were more active than girls (median = 644 counts per minute v 529 counts per minute). Cooper *et al* [206] reported typical physical activity levels of between 200-400 counts per minute in normal, overweight and obese adults from the same geographical region as these children. This indicates that children's activity level is around double that of adults. However, as levels of childhood overweight and obesity are rising, [207-210] it may be that these levels of activity, although higher than adults, are too low to prevent obesity in some children.

9.4.2.2 Light, moderate and vigorous intensity activity

Recommendations for healthy levels of physical activity in children focus exclusively on MVPA (at least 60 min of MVPA daily). The median time spent in MVPA in this study is 20 min/d (25 min/d boys, 16 min/d girls). These figures are considerably lower than those reported for European and US children. Riddoch *et al* [62] reported 192 min/d and 160 min/d in 9 year-old European boys and girls respectively. Trost et al [205] reported that US children achieved 100 min/d of MVPA in the children most closely approximating the age of these children (grades 4-6). Similarly, Pate *et al* [211] reported median values of 146 min/d (boys) and 111 min/d (girls) in 10-year-old US children. These differences are likely to be caused by the use of different cut-points of accelerometer counts to define the lower threshold of moderate intensity activity. These studies all used the Trost cut-point, which ranges from about 1200-1500 counts per minute, depending on age [184]. Guinhouya *et al.* [212] have recently highlighted the wide disparity of conclusions that can be reached when different thresholds for MVPA are applied and have suggested a cut-point of about 3000 to 3700 counts per minute [212]. For example in the present study, using the Trost cut-point [184], estimates of median MVPA are 105 minutes for boys and 72 minutes for girls.

9.4.2.3 Daily and weekly patterns of activity

Children are more active during weekdays compared to weekend days, although differences are small (31 counts per minute). The reasons for this are unclear. Both boys and girls follow similar daily activity patterns. The period 1100-1400 hr seems to be a time when boys are substantially more active than girls on both weekdays and weekend days. During weekdays, the morning travel to school period, lunch break and the immediate post-school period are the key times when children are most active. At the weekend, activity patterns are smoother, without the marked peaks and troughs seen on weekdays.

The most and least active children had similar daily activity patterns, albeit at different levels. The period from the end of school to bedtime (1500 hr onwards) appeared to be when the most active children got their activity. Differences between the most and least active groups exceeded 700 counts per minute and remained substantial throughout the evening period. At the weekends, inactive children exhibit flatter activity profiles of between 200-400 counts per minute throughout the day. Conversely, the most active children show peaks of activity during late morning and mid afternoon.

9.4.2.4 Modifying effects of season and socio-economic factors

Seasonal influences were relatively strong with a summer-winter difference of 108 counts per minute (summer was greater). The Four Seasons study showed a similar difference. Summer physical activity was 93 counts per minute greater than winter physical activity (see Section 9.3.2.2). Fisher *et al.* also reported similar seasonal differences in young children, a range of 125 counts per minute [154]. The most active season was summer.

There was weak evidence for negative associations between social class and mother's education level and physical activity level. Partner's education level demonstrated strong evidence of an association (negative) with activity level. Kimm *et al* [213] reported that lower levels of parental education were associated with greater rates of decline in activity through adolescence in US children. In a study of Scottish children, socioeconomic position was not associated with objectively measured activity levels after adjustment for age, gender, BMI, and month of measurement [134]. Similarly, a systematic review found no evidence of an association between children's physical activity and socioeconomic position [214]. In contrast, children of higher SES (social classes I & II) in Northern Ireland reported higher levels of physical activity than children of lower SES (social classes IV & V) [215]. It is known that socioeconomic conditions in childhood are related to mortality later in life [216] and also the increasing prevalence of childhood obesity has been reported to be strongest in children from lower socioeconomic strata [217]. Ness *et al.* have also reported an inverse association between social class and fat mass in ALSPAC [218]. Conversely, Dummer *et al* [219] have reported no association between obesity and indices of deprivation. From the data reported here, it seems unlikely that these health patterns are explained by differences in activity levels.

9.4.2.5 Sustained bouts of physical activity

In adults, cardiorespiratory fitness is an independent predictor of morbidity and mortality at a higher level than physical activity [220] and frequent sustained bouts of 10-minutes of moderate intensity activity have been shown to have beneficial effects not only on cardiorespiratory fitness, but also on a range of CVD risk factors[221]. In this study, very few children achieved sustained bouts of MVPA. These data support those of Trost *et al* [205] who reported that sustained 10 and 20 minute bouts of MVPA were extremely rare in US children. These results also concur with earlier studies of children using heart rate monitoring,[222] which also demonstrated very low frequency of sustained bouts of activity. It is unsurprising that children do not achieve many sustained bouts of activity, as the natural tempo of their activity is characterised by frequent short bursts of activity lasting just seconds[32].

9.4.3 Strengths of the study

The main strength of this research is the use of an objective measure of physical activity, the Actigraph. This allows for a more precise and accurate measure of physical activity (see Chapter 3), which should enable the detection of associations that cruder instruments, such as, self-report, may miss. The output from the accelerometer is also continuous and this allows for more flexibility in the analyses i.e., analyses using total physical activity or categorisation of activity e.g., using quintiles of physical activity to look for dose response relationships [96]. The clock within the Actigraph also allows minutes of MVPA to be estimated and for daily patterns of physical activity to be described.

9.4.4 Limitations of the study

Accelerometers are an advance in physical activity measurement but they are not the perfect instrument and some types of activity are measured poorly. They perform less well in detecting upper body movement and when walking or running along inclines [223]. It may be that total physical activity is underestimated by accelerometers and that the true levels are higher than reported here. There has been considerable debate on the most appropriate epoch length to use [38]. The concern is that using a one-minute epoch may "mask" the short bursts of vigorous activity that are typical in children [32] by averaging them over one minute. Nilsson *et al.*[180] found that vigorous and very vigorous activity was underestimated when a one-minute epoch was compared with a 5 second epoch. This may result in misclassification of children in these categories of intensity though comparison with this study is difficult as Nilsson *et al.* used different cut-points and classifications for intensity levels [180]. However, this would not affect the main outcome measure of this study, which was volume of physical activity assessed by counts per minute.

9.4.5 Summary

- Children achieved relatively high volumes of activity compared to adults

- Few children achieve the level of MVPA recommended for health, particularly girls

- Little activity is performed in sustained bouts at a level that would promote cardiorespiratory fitness

- These children may be predisposed to the development of childhood obesity, the early onset of CVD risk factors and ultimately chronic disease

9.5 Early life determinants of physical activity in 11-12 year olds: a cohort study

9.5.1 Objectives

The aim of this study was to examine the associations between early life factors (0-5 years) and objectively measured physical activity at age 11 years.

This section will discuss the following:

- Main findings of the study
- Strengths of the study
- Limitations of the study
- Summary

This analysis is known informally as the Determinants study. The methods and results are in Chapter 6 (Section 6.2), Chapter 7 (Section 7.2.5) and Chapter 8 (Section 8.5), respectively.

9.5.2 Birth outcomes

None of the birth outcomes associated with intrauterine growth were associated with later physical activity. A recent study found that low birthweight children (<2500g) reported slightly less weekly minutes of activity at age 10-12 than their higher birthweight peers. The same study, however, reported no difference in sedentary lifestyle by birthweight [125]. Previous studies have found an association between birthweight and childhood obesity [224]; insulin resistance in childhood [225]; fitness [226]; atherosclerosis in adulthood [227] and adult hypertension [228]. Although these risk factors and diseases are associated with physical activity, the evidence presented here suggests that any effect of birthweight is acting through factors other than physical activity.

9.5.3 Prenatal exposures

Several of the prenatal exposures were associated with physical activity though the effect sizes were modest. Maternal but not partner BMI and maternal but not partner obesity were weakly associated with physical activity. Previous studies have been inconsistent. Treuth *et al.* reported no relationship between parental obesity and physical activity assessed by heart rate monitor in 101 prepubescent girls [229]. The systematic review of Sallis *et al.* found that parental obesity was positively associated with physical activity in children aged 4-12 [123].

Maternal and partner smoking were both positively associated with physical activity. This is somewhat surprising since maternal smoking during pregnancy is associated with childhood obesity [224]. The association shown was similar for both maternal and partner smoking and attenuated somewhat after adjustment for SES. It therefore may be due to the social patterning of smoking behaviour. The Descriptives analysis (Section 8.4) showed a negative association between physical activity and SES and it is likely that smoking during pregnancy is an indicator of SES.

Previous studies have reported a positive association between parental activity and children's activity although there is some inconsistency. Sallis *et al.* in their systematic review reported that 11 out of 29 studies showed a positive association between parental physical activity and children's physical activity while the remainder were equivocal in their findings [123]. In our study, maternal activities during pregnancy (specifically brisk walking and swimming) were both positively associated with physical activity at age 11. It is unlikely that this is due to *in utero* biological factors but is more likely that physical activity during pregnancy is a marker for later maternal physical activity, and that this in turn influences children's physical activity.

Parity acts as a proxy for the number of older siblings and this analysis showed that physical activity was positively associated with parity. This confirms the study by Hallal *et al.* who reported that birth order was positively associated with physical activity and negatively associated with a sedentary lifestyle in 10-12 year olds [125].

The association with season of birth is difficult to explain. Children born in summer autumn and winter were more active than those born in spring. Season of birth is associated with a range of mental and physical disorders [230]. Asymmetry in adults is associated with spring and winter births [231]. It is possible that season of birth has an effect through school starting age. In this study some children were measured while at primary school and some while at secondary school where the different environments may provide different opportunities for physical activity. However, it was not possible to control for school type in this analysis. It is also known that a month of birth bias exists in many competitive sports with those born earlier in the sports season [232] and it may be that early involvement in organised sport leads to increased later physical activity [233].

9.5.5 Early childhood (0-2 years) exposures

Neither of the indicators of physical activity at this age (activity at 6 months or time outside at 24 months) were associated with later physical activity. Tracking of physical activity tends to be weak to moderate [234] and it may be that the early measures of physical activity used here lacked precision to detect an association with later physical activity. Parental physical activity at 21 months was associated with children's physical activity at age 11 when two non-active parents were compared with either or both active. There was little difference between having one parent active or both parents active. Previous studies have reported that physical activity tends to aggregate in families [139]. However, the review by Gustafson and Rhodes [133] reported that the evidence for an association between parental and child's physical activity is limited, though few of the studies reviewed used objective measures of physical activity. Motor coordination at 6 months was positively associated with later physical activity though the association was small. A previous study found a weak cross-sectional association between motor coordination and objectively measured physical activity at age four years [235]. These results suggest that little of the variation in children's physical activity at these ages is explained by motor skills.

9.5.6 Preschool (2-5 years) exposures

Few of the pre-school exposures were associated with physical activity at age 11. There was a small effect of TV viewing at both 38 and 54 months after adjustment in model 2. Ekelund *et al.* have recently reported no cross-sectional association between TV viewing and objectively measured physical activity and have suggested that TV viewing and physical activity are separate entities [137]. The meta-analysis of Marshall *et al.* reported a weak relationship between television viewing physical activity (Pearson's R -0.096; 95% CI -0.080, -0.112). Four of the 41 independent samples reviewed (from 24 studies) were cross-sectional [75] so it may be that the modest association we report here is due to the more distal nature of the relationship between television viewing in this sample and the physical activity measurement at age 11 years. Alternatively, publication bias of positive studies may result in the spurious finding of a relationship where none exists.

9.5.7 Effect modification by gender

There was little evidence of effect modification by gender on most of the exposures. Due to the large number of tests for interaction, it is possible that those that did exhibit evidence of effect modification i.e., $P \leq 0.05$ did so by chance.

9.5.8 Strengths of the study

The use of an objective measure of physical activity in the children is a major strength of this study. This allows a more precise and accurate estimate of the level of physical activity and this will, in turn, make it easier to detect small associations that could be missed by less precise measurement of the outcome. The relatively large sample size allowed for adequate exploration of the role of potential confounders and the breadth and depth of ALSPAC data available also allowed for testing for associations of a number of potential determinants that have previously been associated with child and adult health outcomes. The longitudinal nature of the study makes causal associations more likely as the exposures were measured before the outcome. The prospective nature of the study minimises recall bias, as the time between exposures and outcome measurements was about six years at the minimum.

9.5.9 Limitations of the study

Some of the exposure variables e.g., parental physical activity were based on single questions and did not use validated questionnaires. This may have resulted in attenuated associations with children's physical activity at age 11 due to measurement imprecision [37]. It is also possible that cohort attrition and biased participation in the physical activity study has resulted in an unrepresentative sample, which would make it difficult to generalise these results to the general population. It has previously been shown, however, that although children who participated in this study are more likely to be from more socially advantaged backgrounds [1], the magnitude of social patterning in physical activity is small [4]. Several of the exposures were based on questionnaires in which the questions changed slightly over time. For example, categories for time spent outside at 24, 38 and 54 months were different due to these differently framed questions, which makes comparison difficult.

9.5.10 Summary

- This study has shown that a range of early life factors has limited influence on later physical activity in 11 year olds
- The presence of older siblings may encourage physical activity
- The effect of season of birth suggests that some children may be disadvantaged by their relative age when starting school
- Encouraging physical activity in parents may influence their children to become more active

Chapter 10 Overall conclusions and recommendations for future work

10.1 Thesis rationale, aims and objectives

The work that makes up this thesis is part of an ongoing programme with ALSPAC to examine the relationships between physical activity throughout adolescence and various health outcomes including obesity and cardiovascular risk.
The main aims of this thesis were to incorporate an objective measure of physical activity into ALSPAC using the Actigraph accelerometer, and to address some of the questions regarding the interpretation of Actigraph data. To this end, analyses were conducted to estimate the number of days and hours per day required to give reliable physical activity estimates from accelerometer data. The two calibration studies addressed the other aims: to develop cut-points for moderate and vigorous physical activity and to describe the seasonality and intra-individual variation by using a repeat measures design.

One important gap in current knowledge is the identification of any factors early in life that might influence later physical activity. This was the secondary question that this thesis set out to answer. Such knowledge is important in informing interventions that aim to increase children's physical activity and also, ultimately, may inform public health policy. Another secondary aim was to also report the levels and patterns of physical activity in the same children, as this has not been done before using an objective measure of physical activity on such a large cohort of children.

This section will discuss the following:

- Main findings, contribution to exiting knowledge and policy implications
- Strengths of the study
- Limitations of the study
- Recommendations for future research
- Conclusions

10.2 Main findings, contribution to existing knowledge and implications for public health policy

10.2.1 Main findings

The primary aim of this project was to incorporate the Actigraph physical activity monitor into a large, existing longitudinal study and to examine the number of days of measurement needed to ensure adequate reliability while maintaining compliance and preserving a large enough sample for longitudinal analyses. It was found that the Actigraph could be successfully incorporated into ALSPAC with compliance that was comparable with other smaller studies. Different combinations of numbers of days and hours per day needed to adequately represent usual physical activity were examined. Three days gave acceptable reliability (0.7) while maintaining adequate power (>90%).

The two sub-studies answered some further important methodological questions. First, a population-specific cut-point for MVPA was derived that was higher than the most commonly used cut-point (Trost *et al.* [184]) but that was similar to that of several later studies. This has implications for other researchers who want to assess compliance with physical activity guidelines in children of a similar age. Second, the Four Seasons study used a repeat-measures design to assess the variability and seasonality of physical activity over a one-year period. Substantial variability was found in children's physical activity and this should be taken into account by researchers who use a single measurement (as almost all do) to assess physical activity. The ICCs estimated in this study can be used to adjust for regression dilution bias in studies where physical activity is the exposure variable.

There were two secondary aims of this project. The first was to identify associations between factors early in children lives (from pregnancy to about five years) and physical activity at age 11. A range of early life exposure variables was examined but there was little evidence of critical periods of the development of physical activity behaviour. Maternal and partner smoking during pregnancy were both positively associated with physical activity. Children were slightly more active if their parents were active early in the child's life. There were small associations with TV viewing at both 38 and 54 months. Maternal BMI and obesity were both weakly associated with later physical activity. The main finding of this project, therefore, is that little of the variation in physical activity at age 11 was explained by early life factors. It may be that factors more proximal to the time of measurement have a greater influence on physical activity and that these influences change across the life course as people mature and pass major milestones in stages of their lives e.g., from education to work to family life.

Finally, the Descriptives study examined the levels and patterns of physical activity in ALSPAC at age 11 years. Boys were more active than girls. It was found that levels of physical activity were low as few children achieved 60 minutes of MVPA per day. Comparison with other studies was difficult, as many have used the Trost [184] cut-point, which has a lower threshold of moderate physical activity. Cross-sectional associations with season, similar to that found in the Four Seasons study were observed. Small, negative associations with measures of socio-economic status were found that were in the opposite direction to that of many other health behaviours which tend to be positively associated with SES.

10.2.2 Contribution to existing knowledge and implications for research

10.2.2.1 The Methods study

The Methods study showed that it is possible to incorporate an objective measure of physical activity into an existing longitudinal study. Though Actigraphs have been in use for a number of years, there are still methodological issues surrounding the practicalities of using them and the handling of data [38]. The Methods study has gone some way to answering some of these questions. The number of days required to represent habitual physical activity is an important issue and previous smaller studies have shown that a minimum of four days is required to give adequate reliability [177]. The current study took a broader view and chose to slightly relax the commonly used threshold for reliability from 0.8 to 0.7 in order to maintain an adequate sample-size for longitudinal analyses. This allowed for three days as sufficient for a single measurement and the small difference between weekend and weekdays meant that a weekend day was not necessary. For large studies similar to ALSPAC, this will mean that fewer monitors are required as fewer measurement days means a quicker turnaround. However, seven days are still desirable as three days is a minimum threshold and some children will inevitably not comply fully with the study protocol (see Figure 8.1). There was little evidence of reactivity and the differences in physical activity between children with different start days were small and therefore not a major concern for other researchers employing a similar protocol. Children with fewer days of recording tended to have higher total physical activity and though these differences were modest, this does suggest that efforts should be made to encourage children to wear the Actigraph for the whole seven days in order to minimise potential bias. These experiences of data handling and the analyses of reliability and the number of days required to capture habitual physical activity, compliance, and the effects of start days and reactivity should be useful for other researchers wishing to incorporate Actigraphs into similar ongoing studies or when planning new studies. For example, the Millennium Cohort Study [236] is a large study of nearly 20,000 children drawn from across the UK. The researchers in this study are planning to incorporate the Actigraph and are drawing on the analyses presented here and experience of the ALSPAC physical activity team.

10.2.2.2 The Four Seasons study

The Four Seasons study [3] provided valuable information on the variability and seasonality of children's physical activity. The results indicate that there was substantial instability in children's physical activity over one year and this has implications for studies that use a single measurement (the majority) to characterise usual physical activity. Other studies should be aware that children's physical activity is not stable and that there are limitations when using a single measurement. This may be partly addressed by avoiding measurement in only one season of the year although this may be difficult due to time constraints. This study also estimated the ICC, which can be used to correct for regression dilution. That is, when a single measure is used to estimate the "usual" value of a parameter which may vary over time [194]. This may result in under-estimation of the regression co-efficient where, for example, physical activity is the exposure and obesity is the outcome. The regression co-efficient can be corrected by dividing by the ICC. As the ICC in this study is 0.53, this would effectively double the regression co-efficient in the outcome. For example, in the ALSPAC study of physical activity and obesity the observed association between physical activity and fat mass for measurement error, the regression coefficient of the SD score for fat mass per 100 counts per minute increased from -0.11 to -0.22 in boys and from -0.08 to -0.15 in girls [96]. This correction assumes all observed variation in measurements over time is due to measurement error, which may not be the case. Nevertheless, this study does suggest that researchers should consider that intra-individual variation may be attenuating the observed associations in other studies where physical activity is the exposure variable.

10.2.2.3 The K4 and Descriptives studies

The K4 study was designed to derive population-specific cut-points so that accurate assessments of the number of minutes of MVPA can be made. Cut-points for MVPA vary between studies and this can lead to substantial under or over-estimation of the amount of MVPA accrued by subjects [212]. Reilly *et al.* have suggested that age-specific cut-points be used as it is unlikely that a single cut-point will be appropriate due to the changing relationship between accelerometer counts and energy expenditure during growth [191]. The cut-points derived in this project will be useful to other researchers who are assessing physical activity in samples of a similar age to that studied here. The cut-points from this study were used in the Descriptives study to assess compliance with the international recommendations for children and adolescents of at least 60 minutes of MVPA per day (see Sections 6.4 and 8.4). It was found that few children achieved 60 minutes of MVPA per day. Boys reached 25 minutes per day of MVPA while girls achieved 16 minutes per day. This is in contrast to other recent studies using accelerometers that report much higher proportions of time in MVPA. For example, the EYHS reported 192 minutes per day and 160 minutes per day in 9 year-old European boys and girls respectively [62]. Other studies have reported similar amounts to the EHYS of MVPA in children and adolescents [205,211] of a similar age. These differences are probably, in part, due to the different cut-points used to define the lower threshold of MVPA. Guinhouya *et al.* [212] have recently highlighted the wide disparity of conclusions that can be reached when different thresholds for MVPA are applied. Such variation in cut-points does have important implications for physical activity surveillance where the physical activity levels of populations need to be accurately reported. If the cut-point is too low, MVPA will be over-reported leading to the false conclusion that children and adolescents are sufficiently active. Conversely, a cut-point that is too high might lead to the conclusion that populations are too inactive. It may be that the cut-point used in this study is too high and this could be due to over-estimation of resting energy expenditure as discussed in Section 9.2.4. As an illustration, a resting VO_2 of 5 $mL \cdot kg^{-1} \cdot min^{-1}$ (compared with 5.7 $mL \cdot kg^{-1} \cdot min^{-1}$ in the K4 study) would give a cut-point of about 3000 counts per minute for MVPA. This in turn, gives a median (IQR) of 40 (27, 57) minutes of MVPA per day for boys and 26 (17, 28) minutes of MVPA per day for girls. This is equivalent to 22% of boys and 5% of girls meeting the recommended 60 minutes per day of MVPA compared with 5% of boys and 0.4% of girls in the Descriptives study. However, given the very high levels of MVPA previously reported using the widely used Trost *et al.* cut-point [184] it seems likely that this cut-point is too low. As Guinhouya *et al.* [212] point out, in some studies this means that 100% of children are sufficiently active for optimum health which seems unlikely. They also suggest that the "true" cut-point probably lies somewhere between 3000-3700 counts per minute, which is closer to the cut-point reported here. It may be that more extensive calibration studies that follow a more established protocol to estimate resting VO_2 than was practical with this study are needed to settle the issue of where best to place cut-points to estimate MVPA.

The equation to predict energy expenditure will be of use to researchers who wish to examine the associations between energy expenditure and outcomes such as obesity. However, such equations may only be suitable for use at group level [191] and it is likely that they are also population-specific and should therefore be derived in the population for which they are to be used. There is a wide disparity between estimates when different equations are applied on the same population (see Table 9.1)

Though there is some support in the literature [134,214], the small, negative association and lack of association with SES found in this study may be counter-intuitive since many aspects of health such as obesity are positively associated with SES [218]. In adulthood, physical activity is positively associated with SES in some studies [237,238] but it not known at what age this pattern emerges. The small magnitude of social patterning in physical activity in this population should give other researchers confidence that physical activity will have a minimal confounding effect on other socially patterned health outcomes.

10.2.2.4 The Determinants study

There has been little research on the early life determinants of physical activity in children [125]. Much of the research has been cross sectional or longitudinal studies with a shorter follow-up than this study. Only one other paper was identified that looked at early life influences on children's physical activity. The current study examined a range of potential early life determinants. Though few of the exposures examined were associated with later physical activity, there were associations that could potentially inform interventions designed to increase children's physical activity. The associations with parental physical activity early in children's lives suggests that family interventions may be useful in increasing physical activity among children. A recent review concluded that there was no evidence that family based interventions are effective in increasing physical activity among children and only limited evidence that they are effective in adolescents [239]. However, only a small number of family-based trials were identified and these were in ethnic minority groups and lasted 16 weeks or less [239]. From the findings of this project, family-based interventions should begin in the first 21 months of the child's life and be of adequate duration to ensure the development of physical activity habits, have an adequate follow-up and ideally use an objective measure to assess physical activity [239].

10.3 Implications for public health policy

Knowledge of the factors that influence physical activity is important for research purposes i.e., in informing the design of interventions to increase physical activity. This can indirectly inform policy (via the findings from intervention studies for example) but policymakers could also directly use such information. For example, the finding that physically active parents tend to have slightly more physically active children could be used to encourage families to be active together, via public health information programmes. The association between seasonality where the most active children tended to be born in the winter and spring months could contribute evidence to the recently reported plan to allow parents to defer their child's school start year if they are born in the summer months [240]. It is known that such children tend to be at an academic disadvantage and do less well than their elder peers in the same school year [241] and it has also been observed that children born late in the school year tend to do less well at school sport [242]. The difference by season of birth in habitual physical activity shown in this study adds weight to this proposal.

The Descriptives study highlighted some periods during children's days where interventions to increase physical activity may be fruitful. Figure 8.12 on page 141 shows differences between the highest and lowest quintiles of physical activity level throughout the day. The periods where the children are travelling to and from school suggest that encouraging active transport to and from school may increase activity levels in the least active children of this age. Unpublished data from ALSPAC has found that among children living 0.5 to 5 miles from school, walking to school was associated with between 6.0 (95%CI: 3.8; 8.1) and 9.8 (95%CI: 7.5; 12.1) more minutes of MVPA on weekdays than car travellers. This was equivalent to 25 to 40% of the average daily minutes of MVPA. The after school period is also a potential time to target the least active children. This appears to be a time of relatively high activity levels for the most active children and it may be that after school clubs could encourage the least active children to increase their activity levels. Such schemes, like Fitkid in Georgia, USA, have met with some success in increasing fitness and reducing BMI [243]. During school hours may also be an opportune time to target children for physical activity interventions since they are in a controlled environment.

School-based interventions have had some success although this may be restricted to slowing down the decline in activity rather than eliciting an increase [244].

Many interventions to increase physical activity have had limited success. This, then, leads to the question of how levels of physical activity can be increased and whether current interventions that are largely targeted at individuals are worth pursuing or whether a different approach is needed. There has been recent interest in environmental factors and the potential of the built environment to encourage people to increase their activity levels. A recent review has found that the presence of parks, playgrounds and recreational areas; the presence and condition of pavements and bike lanes; and low traffic density and controlled road intersections were all associated with increased physical activity [245]. Modifying the built environment may therefore help to increase levels of physical activity. Such modifications of the built environment in conjunction with verifiably successful individual level interventions may provide the answer to increasing the physical activity of populations.

The Descriptives study highlighted the low levels of physical activity and the fact that few children achieved the recommended 60 minutes per day of MVPA. Policymakers have relied on self or parental report as a surveillance tool for physical activity [246] but the incorporation of the Actigraph into ALSPAC suggests that future surveillance could be carried out objectively and with more precision and accuracy than has been done previously. National studies such as the Millennium Cohort Study in the UK [236] are now beginning to put this into practice, drawing on the experiences of measurement of physical activity in ALSPAC. In the US, the National Health and Nutritional Examination Survey (NHANES) is also using the Actigraph [63]. This should allow for better surveillance of physical activity on a national basis and increasing participation in physical activity and has been a UK government policy since 2002 [15].

10.4 Strengths of the research

The major strength of this research is the use of an objective measure of physical activity. This allows for a more precise and accurate measure of physical activity (see

Chapter 3), which should enable the detection of associations that cruder instruments, such as, self-report, may miss. The output from the accelerometer is also continuous and this allows for more flexibility in the analyses i.e., analyses using total physical activity or categorisation of activity e.g., using quintiles of physical activity to look for dose response relationships [96]. The clock within the Actigraph also allows minutes of MVPA to be estimated and for daily patterns of physical activity to be described.

The large sample size is another strength as this permits adjusting for confounders and analyses for interactions while ensuring that the study is adequately powered and able to detect small associations that may be important at population level. For the study of early life determinants of physical activity, the breadth of ALSPAC data was a major strength as it allowed for the examination of a wide range of potential determinants that is not available to most studies [125].
The longitudinal nature of the determinants study also addressed the issue of the direction of causality. That is, since the exposures preceded the outcomes by a number of years, reverse causality is unlikely, strengthening the evidence that any associations found were casual in nature.

10.5 Weaknesses of the research

Residual confounding is always a risk in observational studies. Potential confounders such as socioeconomic status may be poorly measured and there is a danger that the associations observed may be further attenuated by confounders being only partly adjusted. There is also the danger of attenuation of the observed associations by unknown confounders. For example, there is evidence that genetic factors may be a determinant of physical activity although their role is poorly understood [247]. Twin and family studies have reported a wide range in heritability estimates [248]. The relative contributions of genes and environment to sports participation in youth has been reported to change with age [144]. To date, no single "physical activity gene" has been discovered (although a few have been implicated) [247]. Research into the identification of the genetic determinants of physical activity in children and adults is in its infancy and the ability to control for "genetic factors" is some way off making it impossible, at this stage, to take account of genetic factors. It is possible that genetic factors might confound some of the associations between parental and children's physical activity observed in this study.

Accelerometers are an advance in physical activity measurement but they are not the perfect instrument and some types of activity are measured poorly. They perform less well in detecting upper body movement and when walking or running along inclines [223]. It may be that total physical activity is underestimated by accelerometers and that the true levels are higher than reported here.

There were a large number of statistical tests of association carried out as part of this study. This may result in some spurious associations where none exist, as some associations will be observed by chance. Missing data is also a weakness in this study as with all longitudinal studies. No attempt was made to impute missing data although is possible to do this with accelerometer data [249]. Imputation of missing accelerometer data would have increased the sample size and may also have resulted in less bias in the sample as those who attended the clinic but had no valid data tended to be slightly older, taller and heavier and to come from less advantaged families (see Table 8.4). The differences between participants and non-participants were, however, small so the risk of the results being affected by any bias is small.

Some of the early life exposure variables were from single or a small number questions within a larger questionnaire. Most of these questions were not validated and may lack the precision that a more focused and specific instrument has. For example, the TV viewing questions used four categories (Section 5.2.5) whereas specific TV viewing studies have used as many as 8 categories [250] which allows for more precise estimates.

10.6 Future research

There were few early life factors that were associated with later physical activity, and there are still gaps in our knowledge of what does influence physical activity. There are a number of questions that remain unanswered that could be addressed using ALSPAC. These include the early life determinants of change in physical activity. It is known that children become less active as they age and this is particularly true of girls [251]. The reasons for the differential decline in physical activity among boys and girls are unknown. However, the answer may lie in our evolutionary past. As females mature and reach childbearing age, decreasing energy expenditure through a decline in physical activity may be an effective strategy in order to conserve energy stores for pregnancy and lactation. Although not always possible in hunter-gatherer societies due to the demands of finding food [252], this evolutionary drive to conserve energy may become more apparent in the more sedentary Western society. An alternative, though not necessarily competing, explanation is that social pressures may prevent some girls from participating in physical activity. A recent qualitative analysis reported that girls were concerned about being seen as "aggressive" and "tomboys", particularly by boys, if they were physically active [253]. Thus the reasons for the greater decline observed in girls may be a combination of biological and social factors.

It is also not clear what factors early in children's lives might contribute to this decline. Repeat measures of physical activity are being undertaken in ALSPAC, with assessments at 11 and 13 years completed and the assessment at age 15 is underway. This study only looked at factors up until about the time the children started school. There may be more important, later determinants of physical activity in children such as peers, significant others, school or environmental factors such as access to green spaces or perceived safety. As many of the children in this project were just entering or had yet to enter puberty, it will also be possible to track changes in physical activity as the children go through this change.

Examination of all these factors should give a better understanding of what makes an active child. It is likely that a range of personal and environmental factors and influences throughout childhood and also into adulthood contribute to a person's physical activity habits. The likelihood of discovering a "magic bullet", manipulation of which has a large effect on physical activity is low. With, eventually, three physical activity measurements at ages 11, 13 and 15, and the breadth of potential determinants measured across the lifespan, ALSPAC has the potential to contribute to the literature of research into what makes people active.

Though accelerometers represent an advance in physical activity measurement they do measure some activities less well than others such as cycling, upper body movement and walking on inclines [223]. Some of these issues may be overcome by combining objective measures, for example, accelerometers combined with heart rate monitors in a single instrument, such as the Actiheart, can overcome some of the disadvantages of a single instrument [39]. Such instruments require reliability and validity studies to be conducted before they can be considered for use in the field but they represent a potential advance in understanding the relationship between physical activity and health.

Combining accelerometers with global positioning system (GPS) data and geographic information system (GIS) data may also provide valuable information on the environmental factors that influence physical activity. GPS provides data relating to where the subject is and this can be integrated with the accelerometer data so that it is possible to ascertain where physical activity is being done [254]. This can also be combined with GIS data so that the type of place where the activity is being undertaken so that the potential effects of the built environment can be examined [255].

Despite the improvements in the measurement of physical activity through technological advances, it is unlikely that there will ever be an ideal instrument. It is likely that such advances will continue to improve measurement but as physical activity is a complex and multi-dimensional behaviour, multiple methods, with some being integrated into a single instrument, will continue to be used for the foreseeable future. An example of this is the integration of an accelerometer with a personal digital assistant (PDA) as an intervention tool to promote and also measure physical activity [256]. Such devices offer the opportunity to record the type of participants' activities, in the form of computerised questionnaires, as well as recording how much activity they are doing, thus giving some context to the quantitative measurements of physical activity. Similar instruments could also be manufactured using mobile phones. Such instruments may overcome some issues of compliance as many children and adults carry such devices habitually. Again, integrating GPS recordings with combined instruments would add a further layer of contextual data and help to improve understanding the determinants of physical activity. It should be noted, however, that such complex datasets resulting from the integration of two or more types of data will likely require specialist knowledge to combine and interpret them.

10.7 Conclusions

In conclusion, this study has also shown that it is possible to successfully incorporate the Actigraph into a large, existing longitudinal study and obtain valid data with good compliance. A cut-point for MVPA was also developed in a sub-sample and applied to the whole sample. It was found that few children achieved the recommended 60 minutes of MVPA per day. Variability of children's activity was estimated in a sub-sample of children over one year and was found to be substantial. A range of potential early life determinants of physical activity was examined. Few factors early in children's lives were associated with later physical activity and for those that were, the associations tended to be small. The associations between parental physical activity early in children's lives and later physical activity suggest that encouraging parents to be active might also benefit their children.

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Appendices

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Use of Accelerometers in a Large Field-Based Study of Children: Protocols, Design Issues, and Effects on Precision

Calum Mattocks, Andy Ness, Sam Leary, Kate Tilling, Steven N. Blair, Julian Shield, Kevin Deere, Joanne Saunders, Joanne Kirkby, George Davey Smith, Jonathan Wells, Nicholas Wareham, John Reilly, and Chris Riddoch

Background: Objective methods can improve accuracy of physical activity measurement in field studies but uncertainties remain about their use. *Methods:* Children age 11 years from the Avon Longitudinal Study of Parents and Children (ALSPAC), were asked to wear a uni-axial accelerometer (MTI Actigraph) for 7 days. *Results:* Of 7159 children who attended for assessment, 5595 (78%) provided valid measures. The reliability coefficient for 3 days of recording was .7 and the power to detect a difference of 0.07 SDs ($P \leq .05$) was > 90%. Measures tended to be higher on the first day of recording (17 counts/min; 95% CI, 10–24) and if children wore the monitor for fewer days, but these differences were small. The children who provided valid measures of activity were different from those who did not, but the differences were modest. *Conclusion:* Objective measures of physical activity can be incorporated into large longitudinal studies of children.

Keywords: epidemiology, physical activity, pediatrics, ALSPAC

Background

Physical activity has been defined by Caspersen et al[1] as "any bodily movement produced by skeletal muscles that results in energy expenditure."[(p126)] Evidence accumulated over the last 50 years suggests that regular physical activity in adult life has beneficial effects on health. In particular, regular physical activity is

Mattocks, Tilling, Deere, Saunders, Kirkby, and Smith are with the Dept of Social Medicine, University of Bristol, UK. Ness and Leary are with the Dept of Oral and Dental Science, Bristol Dental School, BS1 2LY, UK. Blair is with the Dept of Exercise Science, University of South Carolina, Columbia, SC 29208. Shield is with the Institute of Child Life and Health, United Bristol Healthcare Trust, Bristol, BS2 8AE, UK. Wells is with the Childhood Nutrition Centre, Institute of Child Health, London, WC1N 1EH, UK. Wareham is with the Medical Research Council Epidemiology Unit, Cambridge, CB2 0QQ, UK. Reilly is with the Division of Developmental Medicine, Yorkhill Hospitals, University of Glasgow, G3 8SJ, UK. Riddoch is with Sport and Exercise Sciences, School for Health, University of Bath, BA2 7AY, UK.

associated with reductions in morbidity from and mortality attributed to coronary heart disease, non-insulin-dependent diabetes and certain cancers.[2] In contrast to the body of evidence on the health benefits in adults, the empirical evidence in children is less extensive.[3,4] This, in part, reflects difficulties in measuring physical activity in children.[5]

Objective methods of assessing physical activity have been developed and offer the opportunity to collect more accurate data in children.[6] Although these methods are increasingly being used in large studies,[7,8] there are still uncertainties about their use. These include the number of hours per day and total number of days of measurement required to characterize usual activity, the likely compliance in large studies (and the resulting potential bias introduced by nonresponse), the potential for instrument reactivity (changes in activity resulting from wearing the instrument), and the potential for bias resulting from differences in number of days of measurement and different start days.

This article describes how we have addressed these uncertainties in the protocols we have adopted for objective measurement of physical activity in a large, prospective study—the Avon Longitudinal Study of Parents and Children (ALSPAC). Some of the protocol decisions were made based on the experience of other groups[7] before the data presented here were analyzed, and some were necessary to fit around the data collection procedures of ALSPAC. For example, the method of dispensing the monitors needed to fit into the ALSPAC clinic schedule and protocols. The longitudinal nature of the study also meant that we were keen to reduce subject attrition in order to maintain statistical power. We recognize that other studies with different designs (eg, intervention studies) and sample sizes might have different requirements, that the methods presented here might not be suitable for some studies, and that the results will not be informative in all circumstances.

Study Design and Methods

Study Population

ALSPAC is a geographically based birth cohort that has been described in detail previously.[9] Briefly, all pregnant women in the former Avon Health Area who had an expected delivery date between April 1, 1991, and December 31, 1992, were asked to take part in the study. A total of 14,541 pregnant women were enrolled, and this resulted in 14,062 live births. Detailed data have been collected by self-completed questionnaires from pregnancy onward. From the age of 7, all children have been invited to regular research clinics.

Ethical Approval and Consent

Ethical approval for the measurement of physical activity was given by the ALSPAC Law and Ethics Committee and the 3 Local Research Ethics Committees. For the physical activity study, verbal consent was given by the child and main carer.

Rationale for Selection of Measurement Instruments

The MTI Actigraph (Manufacturing Technology Incorporated [MTI], Fort Walton Beach, FL) is a uni-axial accelerometer that allows volumes and patterns of physical activity to be measured with substantially increased precision in comparison to self-report methods.[6] The Actigraph has been calibrated in both children and adolescents against heart-rate telemetry,[10] indirect calorimetry,[11] observational techniques,[12] and energy expenditure measured by doubly labeled water.[13]

Data Collection During Pregnancy

At 12 weeks gestation, the mother and her partner were asked about their height and weight (prepregnancy weight for the mother). Body mass index for mother and partner was calculated by dividing weight (kg) by height squared (m^2). At 32 weeks gestation, the mother was asked to record her highest education level and her partner's highest education level (5 categories from basic high school to degree; the 2 lowest categories were combined, giving 4 categories). The mother also recorded the occupation of both herself and her partner, and this information was used to allocate them to social-class groups (classes I to V, with III split into nonmanual and manual, giving 6 categories; the 2 lowest and the 2 highest were combined for the analysis presented here, giving 4 categories) using the 1991 Office of Population Censuses and Surveys classification.[14] Gestational age was estimated using the date of the last menstrual period as reported by the mother at enrollment and the date of delivery. Infant gender and birth weight were recorded at delivery and abstracted from obstetric records or birth notifications.

Data Collection at Age 11

Height and weight of the children at age 11 were measured with a Harpenden Stadiometer (Holtain Ltd, Crosswell, UK) and a Tanita body-fat analyzer and weighing scale (Model TBF 305, Tanita UK Ltd Middlesex, UK). All children who attended the ALSPAC study clinic at age 11 were asked to wear an MTI Actigraph AM7164 2.2 accelerometer for 7 days.

Physical Activity Measurement Protocol

Actigraphs were normally initialized (using Actigraph Reader Interface Unit RIU-41A with RIU software version 2.26B, MTI Health Services, Fort Walton Beach, FL) to start recording at 5 AM on the day following each child's clinic visit. An epoch time of 1 minute was used. Each child was asked to begin wearing the Actigraph on the right hip on the morning following the clinic visit. Children were asked to wear the Actigraphs during waking hours and to take it off only for showering, bathing, or any water sports. Children were asked to post the Actigraph back. A daily time sheet was provided for the child to record the times they put on and took off the Actigraph and the reason for doing so. They were also asked to record any times (in minutes) that they swam or cycled each day. Data from the returned Actigraphs were downloaded using the Actigraph Reader Interface Unit and software. The raw data were then imported using customized software into a Microsoft Access 2000 database. The software produced a series of derived variables describing levels and patterns of physical activity (see Table 1). These variables were chosen because they provide data that will answer some current questions regarding children's physical activity. For example, are current recommendations of 60 minutes per day of MVPA sufficient for maintaining and improving health, and can these be accumulated in short bouts? Cut points for moderate and vigorous physical activity (≥3600 and ≥6200 counts/min, respectively) were derived from a calibration study of 246 children in which Actigraph counts/min were compared with oxygen uptake.[15] The sedentary cut point was similar to that used by Treuth et al,[16] who defined sedentary as <50 counts per 30 seconds. The software used in this study derived categories of physical activity intensity in blocks of 200 counts/min, and sedentary was defined as 0 to 199 counts/min.

Instruments were calibrated with every battery change—about every 6 months. Over the 2-year data-collection period, 267 instruments were used (acquired in batches over the study period), and of these, approximately 15 developed faults during the course of the study. A total of 518 calibrations were carried out according to manufacturers' specifications. Of the 518 calibrations, 394 (77%) required no adjustment.

Data Management

Ten or more minutes of consecutive zeros were regarded as periods in which the monitor was unworn, and these were deleted from each file.[7] If on any 1 day the average counts/min was less than 150 or the average counts/min was more than 3 SDs above the mean,[17] we excluded this day of recording because we considered this level of physical activity to be behaviorally implausible. In our calibration study,[15] the children were asked to walk briskly while wearing an Actigraph (mean walking speed 5.8 kph). Counts/min ranged from 1816 to 7136. The mean plus 3 SDs

Table 1 Descriptive Statistics of Physical Activity Summary Measures Derived From Raw Data

Summary measure	Mean or median	SD or IQR	Range
Number of valid days	5.9	1.2	3–7
Mean total counts	2,758,408	993,916	577,701–7,361,597
Mean total min	4585	1026	1895–6777
h/weekday	13.1	0.9	10.0–18.3
h/weekend day	12.3	1.2	10.0–20.5
Counts/min	604	178	204–1520
MVPA[a,b]	19.7	11.7, 31.0	0.3–125.5
Number of bouts of 5–9 min of MVPA[a]	0.6	0.2, 1.3	0.0–6.4
Number of bouts of 10–19 min of MVPA[a]	0.0	0.0, 0.25	0.0–3.3
Number of bouts of ≥20 min of MVPA[a]	0.0	0.0, 0.0	0.0–1.3
Number of bouts of ≥30 min of sedentary[a,c]	0.7	0.3, 1.2	0.0–4.8

Abbreviations: IQR, interquartile range; MVPA, moderate-to-vigorous physical activity.

[a] Median.

[b] MVPA defined as ≥3600 counts/min.

[c] Sedentary defined as ≤199 counts/min.

before removal of spurious data was 1665 counts/min, and we felt it unlikely that a child could sustain this level of intensity for an entire day. Also, as part of the same calibration study, children were asked to lie still for 5 minutes and then to sit still for 5 minutes while wearing an Actigraph. Although 88% of children managed to lie still enough to accrue no counts and 77% managed to sit still enough to accrue no counts, 6 children did have from 60 to over 100 counts/min for each period of either lying or sitting. We felt it was unlikely that many children could maintain a level of average activity below 150 counts/min over an entire day. A day was considered to be valid if the monitor was worn for at least 600 minutes.

Statistical Analyses

Statistical analyses were carried out using Stata Version 8.0 for Windows (Stata Corporation, College Station, TX). Means and standard deviations were calculated for continuous variables and proportions were calculated for categorical variables. Differences between continuous variables were tested using *t* tests and analysis of variance (ANOVA), and differences between categorical variables were tested with chi squared tests. The number of days of monitoring and the number of minutes per day required to achieve reliabilities of .7, .8, and .9 were calculated using the Spearman–Brown prophecy formula,[18] which uses the intraclass correlation coefficient (ICC) as a measure of reliability. The ICC is defined as the ratio of between individual variance to the sum of the between- and within-individual variance.[18] The ICC for a single day of monitoring was calculated from formula (1), where σ_b^2 is the between individual variance and σ_w^2 is the within individual variance.[19]

$$(1)\ ICC_s = \sigma_b^2/(\sigma_b^2 + \sigma_w^2)$$

The formula for estimating the number of days of measurement to achieve a specified reliability is shown in equation (2), where N is the number of days required to achieve ICC_t, the desired reliability, and ICC_s is the single day ICC from equation (1).

$$(2)\ N = [ICC_t/(1 - ICC_t)][1 - ICC_s/ICC_s]$$

Power to detect a difference of 0.07 SDs ($P \leq .05$) in counts/min between any 2 groups was also calculated for various combinations of numbers of days of measurement and hours per day. To test for instrument reactivity, we used a linear regression model that specifically allowed for clustering in the data to examine associations between total activity and day of measurement. The cluster option was used with the regress command in Stata to specify that the observations were independent across groups (ie, individuals) but not within groups. This allows for repeated observations on individuals without violating the assumption of independence in the data.[20]

Results

A total of 11,952 children were invited to come to the 11-year clinic, of whom 7159 (60%) came for assessment and 6622 (93%) agreed to wear an Actigraph (Figure 1). Some of the variables derived by the macro are summarized in Table 1.

Number of Minutes and Days of Measurement

Table 2 shows the reliability coefficients for different combinations of number of days and number of minutes per day. The single-day ICC for 600 minutes of measurement was .45. Single-day ICCs (from equation (1)) for different numbers of minutes per day were similar. Table 3 shows power (to detect a difference of 0.07 SDs in counts/min between any 2 groups, $P \leq .05$ to .07 SDs is equivalent to

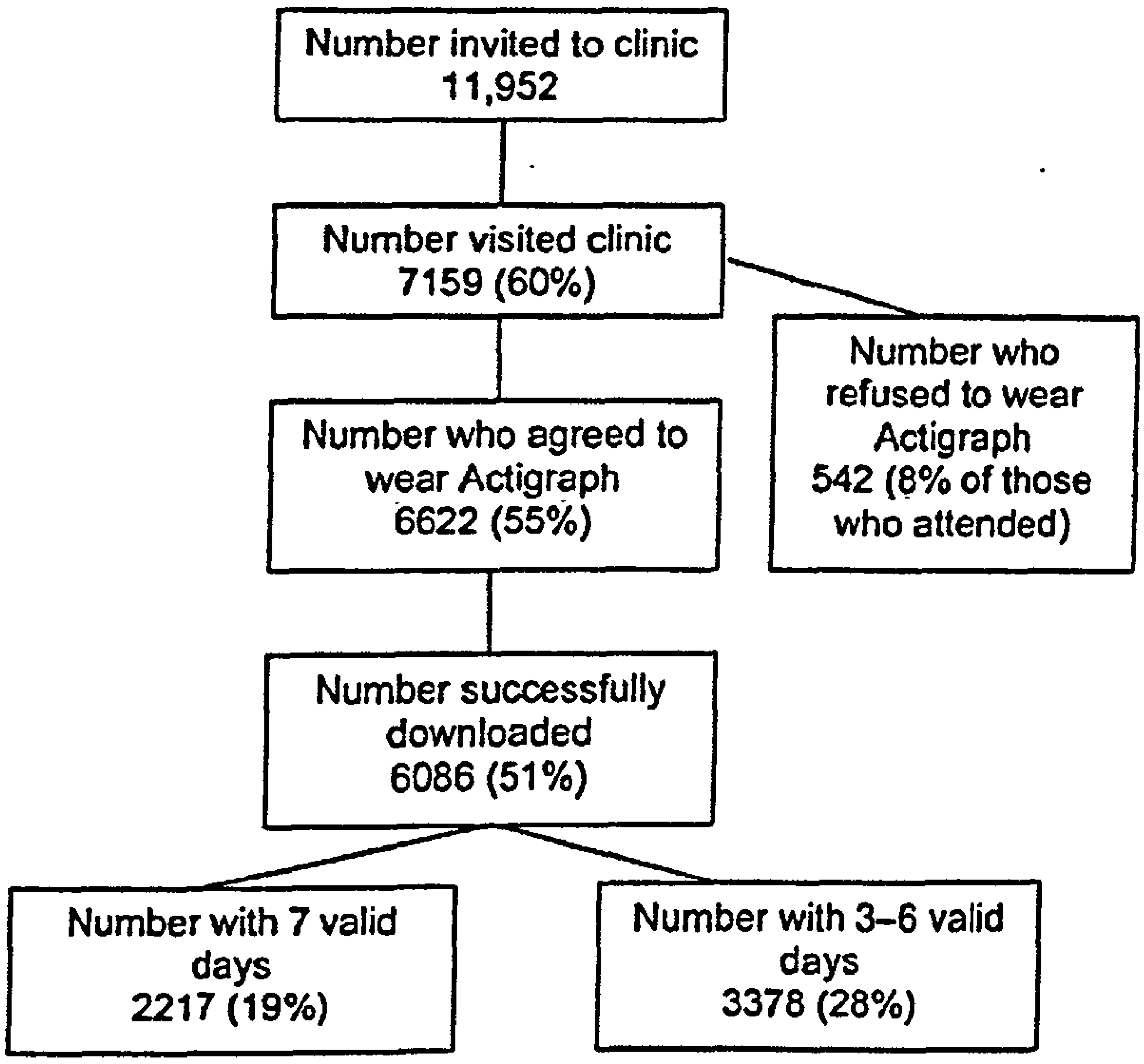

Figure 1 — Flow of physical activity study participants through the ALSPAC clinic

Table 2 Reliability of Different Combinations of Minutes per Day and Days of Measurement

		Days of measurement[b]		
min/day	ICC[a]	$R = .7$	$R = .8$	$R = .9$
600	.45	2.9	4.9	11
540	.44	3.0	5.1	11.5
480	.44	3.0	5.1	11.5
420	.43	3.1	5.3	11.9

Abbreviations: ICC, intraclass correlation coefficient (interindividual variation/total variation).

[a] Based on maximum number of valid days available.

[b] Predicted by Spearman–Brown prophecy formula.

Table 3 Power and Sample Size for Different Combinations of Minutes per Day and Days of Measurement

	Number of days							
	≥3 (any type)		≥3 (≥2 weekday + ≥1 weekend)		≥5 (any type)		≥5 (including ≥1 weekend)	
min/day	N	Power[a] (%)	N	Power (%)	N	Power (%)	N	Power (%)
600	5601	90.8	4980	87.4	4760	89.7	4543	88.3
540	5717	91.7	5284	89.5	5073	91.9	4924	91.1
480	5780	91.9	5448	90.4	5284	92.8	5172	92.3
420	5812	92.3	5529	91.1	5397	93.7	5304	93.3

[a] Power to detect a difference of .07 SDs in counts/min between 2 groups ($P \leq .05$). One SD = 178 counts/min; .07 SD = 13 counts/min.

about 13 counts/min in our sample) and sample size for different combinations of number of days of measurement and number of minutes per day. Weekday mean counts/min was slightly higher than weekend mean counts/min (16 counts/min; 95% CI, 10–22), based on those with at least 3 days recording. Examination of various combinations of days and minutes per day (540, 480, and 420 minutes) revealed little difference in power. An *a priori* decision to specify a valid day as 600 minutes was taken in order to reduce variation in day length and its potential to affect counts/min and sedentary and light activities[21] and to allow direct comparison with the European Youth Heart Study that used the same criteria.[7] Data were considered valid if a child had at least 3 days of at least 600 minutes per day recorded. This combination gave reasonable reliability (Table 2), power >90% (Table 3), and ensured a sufficient sample size for future analyses. Although a weekend day was not specified in order to fulfill validity criteria, 90% of children had at least 1 weekend day of recording.

Final Numbers With Valid Measurement

Applying the above criteria gave us a final sample of 5595 returned Actigraphs that satisfied the validity criteria—2662 boys and 2933 girls (Figure 1). Of the 1027 children who were excluded, 171 were excluded because of broken or malfunctioning instruments and the remainder because the monitor was worn for an insufficient amount of time.

Differences Between Participants and Nonresponders

Children who provided valid recordings differed from children who failed to provide valid recordings in terms of age, weight, body mass index, sex, and pubertal status, but the size of the differences were small (Table 4). More girls than boys returned instruments with valid data (81% of girls versus 76% of boys; $P < .001$). Parental variables were not strongly associated with compliance. Children were more likely to comply if their mothers had a higher level of education, but again, the differences were small.

Table 4a Comparison of Children Who Had Valid Data With Those Who Did Not, Continuous Child Variables

Characteristic	Attended clinic but did not have valid data, N = 1564, mean (SD)	Attended clinic and had valid data, N = 5595, mean (SD)	*P* value
Age (y)	11.81 (0.26)	11.77 (0.23)	<.001
Height (cm)	151.1 (7.3)	150.7 (7.2)	.097
Weight (kg)	44.9 (11.1)	43.5 (9.9)	<.001
Body mass index (kg/m^2)	19.5 (3.8)	19.0 (3.3)	<.001
Birth weight (g)	3445 (537)	3433 (523)	.43

Table 4b Comparison of Children Who Had Valid Data With Those Who Did Not, Categorical Child Variables

	Attended clinic but did not have valid data, N = 1564, percentages	Attended clinic and had valid data, N = 5595, percentages	*P* value
Gender (male)	53.7	49.1	<.001
Pubertal stage (% above Tanner stage 1)	73.6 (70.3, 76.9)	78.2 (76.7, 79.7)	.009
Parity[a]			
0	43.8	43.4	.66
1	32.0	32.3	
2	13.2	12.4	
≥3	11.0	11.9	

[a] Parity was recorded at 18 weeks of gestation by self-report questionnaire and is defined as the number of previous pregnancies resulting in live or still births.

Table 4c Comparison of Children Who Had Valid Data With Those Who Did Not, Continuous Parental Variables

	Attended clinic but did not have valid data, N = 1564, mean (SD)	Attended clinic and had valid data, N = 5595, mean (SD)	*P* value
Maternal height[a] (cm)	164.3 (6.8)	164.2 (6.6)	.50
Maternal BMI[a] (kg/m^2)	23.0 (3.9)	22.9 (3.7)	.34
Paternal height[a] (cm)	176.0 (7.1)	176.4 (6.8)	.06
Paternal BMI[a] (kg/m^2)	25.1 (3.3)	25.1 (3.3)	.96
Maternal age	29.0 (4.8)	29.0 (4.6)	.78

Abbreviation: BMI, body mass index.

[a] Maternal and partner height and body-mass-index data were from self-report questionnaire at 12 weeks of gestation.

Instrument Reactivity, Number of Days of Measurement, and Start Day

The mean difference between total activity on day 1 and the mean of total activity on the remaining days was 17 counts/min higher on day 1 (95% CI, 10–24) or about 0.1 SD. Linear regression, allowing for multiple measurements per child, indicated that day 1 of measurement tended to show slightly higher activity levels than subsequent days (*P* for trend <.001). This remained unchanged after adjustment for gender. There was a difference between the activity levels of children with different numbers of valid days of measurement, and this increased slightly after adjustment for confounding factors (Table 5). There were also differences in total

Table 4d Comparison of Children Who Had Valid Data With Those Who Did Not, Categorical Parental Variables

	Attended clinic but did not have valid data, N = 1564	Attended clinic and had valid data, N = 5595	*P* value
Social class[a]			
1	27.8	29.7	.19
2	26.2	27.2	
3	29.5	26.6	
4	16.6	16.5	
Maternal education[a]			
1	14.5	16.4	.04
2	26.6	26.7	
3	34.4	35.8	
4	24.5	21.1	
Paternal education[a]			
1	21.9	22.0	.66
2	27.6	28.6	
3	21.2	21.9	
4	29.2	27.5	

[a] Socioeconomic variables and parental education from self-report questionnaire at 32 weeks of gestation (coded as 1 = highest, 4 = lowest).

Table 5 Mean Counts/Min by Number of Days of Measurement and by Start Day

Number of valid days	Mean counts/ min[a,c]	Frequency	Mean counts/ min[b,c]	Frequency
3	630	314	618	130
4	622	527	636	269
5	619	951	626	488
6	603	1586	606	828
7	590	2217	595	1291
Total	604	5595	608	3006
	$\beta = -11$ (−14, −7), $P < .001$		$\beta = -11$ (−16, −6), $P < .001$	

Start day	Mean counts/ min[a,c]	Frequency	Mean counts/ min[b,d]	Frequency
Monday	558	112	601	62
Tuesday	602	486	599	255
Wednesday	628	997	627	533
Thursday	608	924	620	479
Friday	605	955	602	526
Saturday	607	979	604	549
Sunday	582	1142	592	549
Total	604	5595	608	3006

[a] Unadjusted.
[b] Adjusted for age, gender, pubertal status, body mass index, and maternal and paternal education level and social class.
[c] $P = .001$.
[d] $P = .007$.

activity levels depending which day measurement started on (Table 5). There was a small difference in activity depending on whether children started on a weekday or weekend day (mean difference 17 counts/min; 95% CI, 7–29, $P < .001$). This represented about 0.1 of a SD. A total of 3474 children (62%) started on a weekday, and 2121 (38%) started on a weekend day.

Discussion

The study provides an overview of the accelerometry processing and compliance patterns in a large study of children. We have shown that 3 days of measurement resulted in good reliability and power and that systematic differences in counts/min between numbers of days of measurement were small. Furthermore, we have described the characteristics of children who completed the protocol and those that did not and have shown that these differences were modest. There was some potential for bias depending on which day of the week children started wearing the Actigraph.

Compliance With the Study Protocol

Of the children who attended the 11-year clinic, 78% provided valid data. This is consistent with results from previous studies. Riddoch et al measured physical activity in 9- and 15-year-old children in 4 European countries. Using similar procedures to this study to exclude nonvalid data, 75% of children who took part in the study had valid data for at least 3 days for at least 10 hours per day.[7] In a feasibility study of accelerometry in children from grades 6 through 8, Van Coevering et al found that 234 of 282 children (83%) provided 3 valid days of recording.[8]

Number of Days of Measurement and Start Day

The use of 3 days of physical activity measurement gave good reliability ($R = .7$; Table 2). Although it has been previously suggested that a minimum of 4 days of measurement is required to give a .8 reliability coefficient,[22] we feel that a reliability coefficient of .7 is acceptable and justified on the basis that it maximizes power and reduces the number of participants excluded for future analyses. The small difference in counts/min between weekdays and weekend days and similar power suggests that including a weekend is not necessary in our sample, although this might not be the case for smaller studies. Similar single-day ICCs for different minimum acceptable day lengths gave similar estimates for the number of days required to achieve prespecified reliabilities. Despite this, 600 minutes was chosen as the minimum day length as it (1) minimizes the possible effects of varying day length on physical activity outcomes and (2) allows comparison with other studies. Use of the Spearman–Brown formula does have some limitations as it relies on compound symmetry (ie, the variances for each day are equal and correlations between pairs of days are equal.)[23] Correlations for counts/min between pairs of days in this study ranged from .39 to .48, and we feel that this range in the data is unlikely to constitute a problem.

Children with fewer days of recording tended to have higher total physical activity (counts/min), but these differences were modest; the biggest difference

(40 counts/min or about 0.2 SDs) was between 3 days of measurement (the minimum) and 7 days of measurement (the maximum). We found that there were differences in total counts/min depending on the start day. Children who started on a Monday had the lowest counts/min, and children who started on a Wednesday had the highest counts/min. Saturday was the most popular day to attend the clinic, and counts/min was also lower than average when children started on this day. This is difficult to explain and might represent a chance finding, although it might be that children with a Monday start day were a different group from the rest because there was no clinic on Sundays, and a Monday start day had to be specifically requested. There was also a difference in activity depending on whether children started on a weekday or weekend day, although the difference was small (17 counts/min or 0.1 SDs).

Instrument Reactivity

Reactivity (the tendency of the instrument to modify normal behavior) has been highlighted as a potential problem in the measurement of physical activity.[19] Although a difference in total activity between the first day and the mean of all subsequent days was found, this was small at 17 counts/min (about 0.1 SDs) and it is unlikely that this would introduce bias into this study.

Differences Between Participants and Nonresponders

There were small differences between children with and without valid Actigraph data. Boys were less likely to provide valid data, and children with valid data had lower body mass index, although the difference was small. This is in contrast to Van Coevering et al who found that overweight children were more likely to provide 7 days of complete data.[8] Children with valid data tended to be younger and lighter, and more children with valid data were in later stages of pubertal development compared with those who did not provide valid data, but again, these differences were small. There were also some differences in terms of maternal education—a marker of socioeconomic position. Those who provided valid data tended to have mothers with higher educational levels. The difference was small, however, and unlikely to introduce bias because the association between socioeconomic position and physical activity in children in this population is weak and inverse (ie, lower socioeconomic position is associated with slightly higher total physical activity).[24] These results suggest subject characteristics that might be targeted to maximize compliance.

Limitations of the Study

Because of the large volume of data collected, it was not possible to examine each Actigraph file individually to check for errors. This might have resulted in spurious patterns of data being accepted as valid. However, we feel the stringent exclusion criteria for dealing with outliers during the data cleaning kept implausible data to a minimum. Most studies, including ours, use a 1-minute measurement epoch. There has been considerable debate on the most appropriate epoch length to use.[19] The concern is that using a 1-minute epoch might mask the short bursts of vigorous activity that are typical in children[25] by averaging them over 1 minute.

Nilsson et al[26] found that vigorous and very vigorous activity was underestimated when a 1-minute epoch was compared with a 5-second epoch. This might result in misclassification of children in these categories of intensity. This would not, however, affect the main outcome measure of this study, which was volume of physical activity assessed by counts/min.

Although we feel that the results of our study will be informative for other researchers when deciding on study methodology, we recognize that our analyses and the decisions we made might not be appropriate for all studies. For example, our relatively large sample maximized power and gave reasonable reliability with 3 days of recording. A duration of 3 days is shorter than has previously been recommended,[22] although other large studies have used 3 days.[7] Studies with smaller sample sizes might wish to measure a greater number of days and to process data by hand to improve measurement precision.

Conclusions

We have demonstrated the feasibility of incorporating an objective measure of physical activity into a large, ongoing birth cohort. The use of an objective measure of physical activity in this large field-based study of children will allow us to describe the determinants of physical activity at age 11 and to examine the health consequences of physical activity in children more accurately than has previously been possible. Furthermore, we have reported on a number of design issues and how they affect the validity of accelerometer data, which will be of use to researchers who wish to use accelerometry in large studies of children.

Acknowledgments

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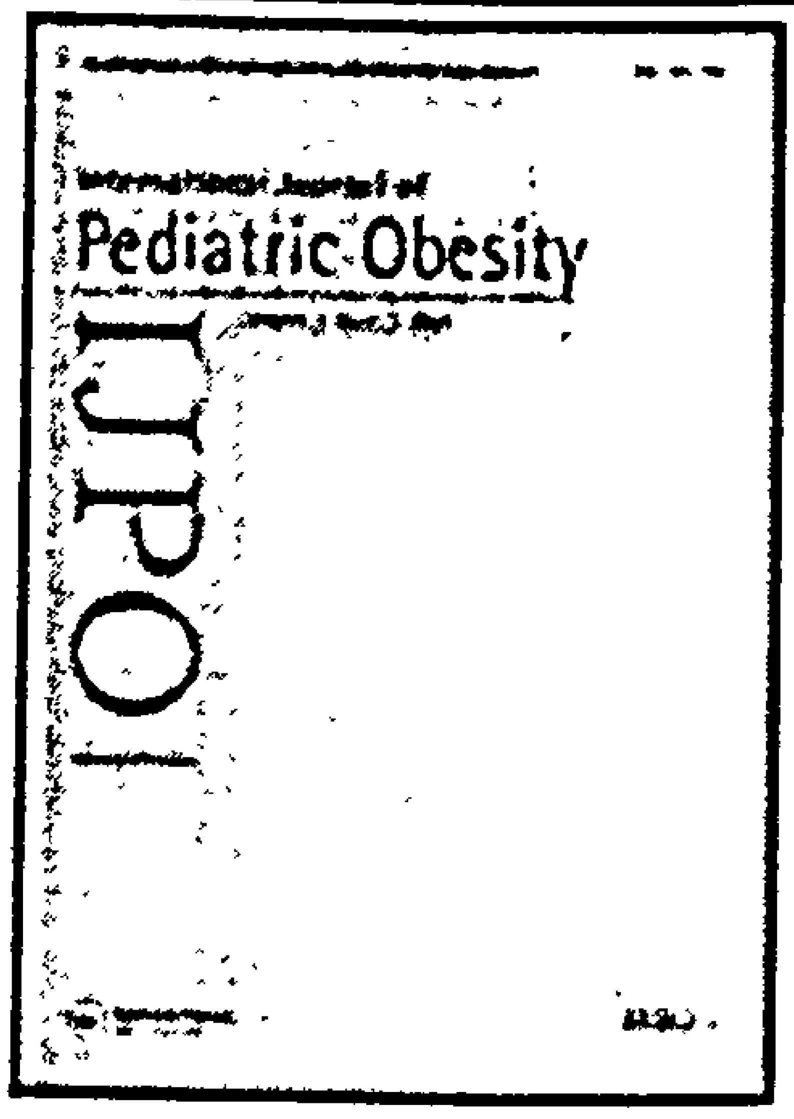
Appendix 2



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Calibration of an accelerometer during free-living activities in children

Calum Mattocks [a]; Sam Leary [a]; Andy Ness [b]; Kevin Deere [a]; Joanne Saunders [a]; Kate Tilling [a]; Joanne Kirkby [c]; Steven N. Blair [d]; Chris Riddoch [e]

[a] Department of Social Medicine, University of Bristol, England
[b] Department of Oral and Dental Science, University of Bristol, England
[c] Institute of Diet, Exercise and Lifestyle University of Glasgow, Glasgow, England
[d] University of South Carolina, Bath, England
[e] University of Bath, Bath, England

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ORIGINAL ARTICLE

Calibration of an accelerometer during free-living activities in children

CALUM MATTOCKS[1], SAM LEARY[1], ANDY NESS[2], KEVIN DEERE[1], JOANNE SAUNDERS[1], KATE TILLING[1], JOANNE KIRKBY[3], STEVEN N. BLAIR[4] & CHRIS RIDDOCH[5]

[1]*Department of Social Medicine, University of Bristol, England,* [2]*Department of Oral and Dental Science, University of Bristol, England,* [3]*Institute of Diet, Exercise and Lifestyle University of Glasgow, Glasgow,* [4]*University of South Carolina,* [5]*University of Bath, Bath, England*

Abstract

Objective. The aims of this study were to develop an equation to predict energy expenditure and to derive cut-points for moderate and vigorous physical activity intensity from the Actigraph accelerometer output in children aged 12 years. *Methods.* The children performed a series of activities (lying, sitting, slow walking, fast walking, hopscotch and jogging) while wearing an Actigraph and a portable metabolic unit. The sample was divided into a developmental and a validation group. Random intercepts models were used to develop a prediction equation in the developmental group. The equation was assessed in the validation group by calculating limits of agreement (actual minus predicted energy expenditure). Thresholds for moderate and vigorous activity were derived by refitting the energy expenditure model with VO_2 as the outcome. *Results.* The developmental group comprised 163 children, while the validation group comprised 83 children. The equation, adjusted for age and gender, adequately predicted energy expenditure from accelerometer counts. Physical activity intensity cut-points were derived from resting VO_2. The lower threshold for moderate intensity (four METs), adjusted for age and gender, was 3581 counts per minute. The lower threshold for vigorous activity (six METs) was 6130 counts per minute. *Conclusion.* The prediction equation and the derived cut-points will help to better interpret the output of the Actigraph in children aged 12 years. The cut-point for moderate to vigorous physical activity is higher than that reported previously.

Key words: *Child, energy metabolism, measurement, physical activity, validity, ALSPAC*

Introduction

Objective measurement of physical activity is now feasible in large studies (1) providing an increased level of measurement precision that may lead to more accurate assessments of the relationships between physical activity and health (2). This is a particular advantage in studies of children where traditional epidemiological methods of assessing physical activity, such as self-report, perform poorly (3).

The Actigraph (Actigraph, LLC, Fort Walton Beach, Florida) accelerometer is one objective method that has been successfully used in large studies with children (1,4). However, difficulties in translating Actigraph output into energy expenditure and defining cut-points for physical activity intensity potentially limit interpretation of the data (5). A better understanding of the relationships between Actigraph counts and energy expenditure and physical activity intensity should allow more accurate estimations of the amount of time children spend in moderate to vigorous physical activity (MVPA).

Several calibration studies of the Actigraph to develop energy expenditure prediction equations have been carried out in children, although the study designs have varied (6–15). Some were conducted in free-living situations (6,8), some in laboratories (9, 10,14), and one in both (9). Studies that have derived cut-points to define intensity thresholds in children have reported different cut-points (7,9,12,13,15); studies were generally small or were

Correspondence: Calum Mattocks, Avon Longitudinal Study of Parents and Children (ALSPAC), Department of Social Medicine, University of Bristol, 24 Tyndall Avenue, Bristol, BS8 1TQ, UK. Fax: 44 117 928 8138. E-mail: c.mattocks@bristol.ac.uk

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confined to one gender. Some studies restricted the ages of subjects while others included a range of ages. The age of subjects may be important, as it has recently been suggested that equations may vary by age (16).

The aims of this study were a) to develop an equation to predict energy expenditure from accelerometer counts in peripubertal children and b) to derive population-specific cut-points defining the lower thresholds for moderate and vigorous intensity physical activity.

Methods

Children were recruited from the Avon Longitudinal Study of Parents and Children (ALSPAC). This is an ongoing, geographically-based, birth cohort that has been described in detail elsewhere (17). Briefly, 14541 pregnant women living in one of three Bristol-based health districts in the former County of Avon, with an expected delivery date between April 1991 and December 1992, were invited to take part. Detailed information has been collected from pregnancy onwards using self-administered questionnaires, data extraction from medical notes, linkage to routine information systems and at a regular clinic lasting three hours, which the children have been invited to attend from the age of seven years. Ethical approval for this study was obtained from the ALSPAC Law and Ethics Committee and Local Research Ethics Committees. This study was carried between June 2004 and July 2005.

Children, aged 11 years, who came to the annual ALSPAC clinic between January 2003 and January 2005 were asked if they would be willing to take part in an unspecified further study (they were, however, aged 12 by the time of this study). Those that agreed were stratified into four groups according to gender and body mass index (BMI) (BMI below or above the medians of 17.6 kg/m^2 for boys and 18.8 kg/m^2 for girls) in order to ensure a balance between gender and body size in the sample. Equal numbers of children were randomly selected from each of these strata and invited to participate in this study. An invitation letter was sent to the selected children, along with a detailed information sheet that explained the nature of the study.

Children who agreed to participate were contacted by telephone and a study appointment made. The children were asked not to eat or drink for at least one hour prior to their visit and to wear clothing appropriate for exercise. Children were accompanied by a parent, and were asked to respond verbally to questions from a modified physical activity readiness questionnaire (PAR-Q) (18) to confirm their suitability to participate. The test protocol was explained and parents gave written informed consent, while children gave written assent. Height was measured to the nearest 0.1 cm (Leicester Height Meter, Invicta Plastics, Leicester, UK) and weight to the nearest 0.1 kg (Seca 770, Hamburg, Germany). BMI was calculated by dividing weight (kg) by height (m) squared. Children were then fitted with the Actigraph and a portable metabolic unit (Cosmed K4b^2; Cosmed, Rome, Italy) and were given approximately five minutes to become familiar with wearing the equipment.

The Cosmed K4b^2 measures breath-by-breath ventilation (V_E), fraction of expired oxygen ($F_E O_2$) and carbon dioxide ($F_E CO_2$). The unit weighs 1.5 kg and is held in a chest harness. Expired gases are collected via a mask and sampled by O_2 and CO_2 analysers. The instrument was calibrated in accordance with the manufacturers instructions. The Cosmed K4b^2 has been validated in children with small, positive biases reported in VO_2 of less than 6% during walking and running (19).

The Actigraph 7164 is a uni-axial accelerometer that uses a piezoelectric lever to detect acceleration ranging from 0.05 to 2.13 G. As the subject moves, the lever flexes and a signal is generated in proportion to the amount of acceleration, thus both the frequency and intensity of movement are combined in the output. The signal generated is sampled 10 times per second and the values summed over a user-specified 'epoch' that can range from one second to one minute (20). A single instrument was used throughout the study with the epoch set at 10 seconds. As the study ran over one year, the instrument calibration was checked twice during this period using the manufacturers' calibrator (CAL 71, Actigraph, LLC, Fort Walton Beach, Florida). On both occasions no adjustment was required. The Actigraph was attached to the child with an elastic belt and positioned on the right hip. The instrument was initialised prior to each test and downloaded immediately afterwards onto a computer using the manufacturers' Actisoft software version 3.2 (Actigraph, LLC, Fort Walton Beach, Florida).

The exercise tests were performed indoors. Children were asked to perform six activities, each of which lasted for five minutes. Table I describes these activities in the order they were carried out. The activities were selected to provide graded increases in intensity and to reflect the type of locomotor activities that comprise the majority of children's activity (21). Hopscotch was included to simulate a sporadic jumping, bending and stretching type of activity. Apart from lying and sitting, all activities were self-paced in order to better reflect free-living conditions. Walking and jogging activities took place around an indoor jogging track. Lying and sitting

Table I. Descriptions of physical activities performed by the children.

Activity		Description
1	Lying	Child lay on a gym mat on a bench with a pillow
2	Sitting	Child sat on the bench and played a hand-held video game
3	Slow walking	Child walked at own pace but told to "walk slowly"
4	Brisk walking	Child walked at own pace but told to "walk briskly"
5	Jogging	Child jogged at own pace
6	Hopscotch	Child played hopscotch at own pace

were on a 'bench' with an exercise mat to lie on at the side of the jogging track. Children progressed through the activities without stopping apart from for the hopscotch activity. Walking and jogging speeds were calculated by using markers every 5 m on the jogging track and calculating speed from distance travelled and the length of time taken.

Data from the Actigraph were imported into an Excel spreadsheet using the Actigraph Actisoft software. Data for each test from the Cosmed K4 unit were downloaded using the manufacturers' Data Management Software version 7.3a at the end of each test and subsequently imported into an Excel spreadsheet. Data from both the Actigraph and the Cosmed spreadsheets were then imported into an Access database using a customised macro. The macro summed the Actigraph counts from minutes 3 ½ to 4 ½ (i.e. the total of six 10 second epochs) for each activity in order to allow oxygen uptake to stabilise. This was matched with the mean of the corresponding minute of the K4 data. Half minutes were used to avoid any change in counts or oxygen uptake as children changed from one activity to the next. One minute of each five-minute activity was used in order to allow VO_2 to stabilise after the previous activity. Energy expenditure ($kJ \cdot kg \cdot min^{-1}$) was calculated from VO_2 using the Weir formula (22) divided by weight (kg).

Statistical analyses

Statistical analyses were carried out using Stata Version 8.0 for Windows (Stata Corporation, College Station, Texas). Means and standard deviations were calculated for normally distributed variables and medians and interquartile ranges (IQRs) for skewed variables, and percentages for categorical variables. Pearson correlation coefficients were used to assess relationships between normally distributed continuous variables.

Prediction of energy expenditure

Sixty-six percent ($n=163$) of the children were randomly selected to create a developmental group. The equation for predicting energy expenditure from counts per minute was derived using a random intercepts model. A random slopes model was initially tried but the slopes did not vary sufficiently. The model was fitted with and without adjusting for potential confounders age and gender. Backwards elimination was used to see if either of the potential confounders could be removed. Interaction between gender and counts was formally tested by including an interaction term in the model. The remaining children were allocated to the validation group ($n=83$). The validity of the equation was assessed by calculating limits of agreement (23) for actual and predicted energy expenditure (mean difference ± 2 SDs of the difference, with the difference calculated as actual-predicted energy expenditure). Limits of agreement were also calculated in the developmental group for comparison.

After validation of the equation, all remaining analyses were undertaken on the developmental group only. From the prediction equation, residuals were calculated, their distribution checked for normality, and they were plotted against predicted values, to ensure the model fitted adequately.

Derivation of activity intensity cut-points

The prediction equation, with and without confounders, was then refitted using VO_2 as the outcome instead of energy expenditure, in order to derive threshold values of counts per minute for moderate (three and four METs) and vigorous (six METs) intensity. For moderate intensity, cut-points were derived for both three and four METs. Three METs was included to allow for comparison with other studies. However, there is evidence that four METs is a more appropriate cut-point. Treuth et al. found that girls with a mean age of 14 were working at the lower end of 40–60% VO_{2max} (which defines moderate intensity activity) and that this was equivalent to 4.3 METs during brisk walking at 3.5 mph (5.6 kph) (7). This is similar to our mean self-selected brisk walking speed of 5.8 kph. Similarly, Harrell et al., in children of a similar age, reported that walking at 5.6 kph elicits 4.3–4.7 METs (19).

We used the conversion 1 MET = baseline VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$); the minimum of lying or sitting VO_2 was taken for each child, and the mean for all children used as the baseline. When confounders were included in the equation, they were centred to allow predictions to be made for the 'average' child.

Table II. Characteristics of study sample.

Characteristic	All (N = 246)	Boys (N = 110)	Girls (N = 136)
Age (years)[a]	12.4 (0.2)	12.4 (0.2)	12.4 (0.2)
BMI (kg/m^2)[b]	18.7 (17.1, 21.2)	18.6 (17.1, 21.0)	18.9 (17.3, 21.3)
Height (cm)[a]	150.3 (6.8)	149.9 (7.3)	150.6 (6.3)
Weight (kg)[b]	41.6 (35.4, 47.8)	41.2 (34.4, 47.0)	42.3 (36.4, 48.3)
Social class (% non-manual)	56	56.3	55.8

[a] Mean (standard deviation).
[b] Median (interquartile ranges).

Cut-points were calculated for the whole developmental group (with and without confounders), and males and females separately. Sensitivities and specificities based on children in the validation group were also calculated from the resulting threshold values, using the VO_2 MET values as the gold standard.

Results

Of the 257 who volunteered to participate, 246 were included in the analysis. Eight were excluded due to equipment failure and three due to insufficient compliance with the protocol. Of those who were included in the analysis, 11 did not complete the hopscotch and 20 did not complete the jogging. Additionally, one sitting VO_2 that was unusually high, plus two slow walking and one walking VO_2 values that were unusually low, were excluded. Data were approximately normally distributed therefore no transformations were required.

Table II summarises the characteristics of children who took part in the study.

Table III shows the numbers of children from the whole sample who completed each activity along with the mean (standard deviation, SD) values for walking and jogging speeds; Actigraph counts per minute, energy expenditure (kJ·kg·min^{-1}) and VO_2 (mL·kg^{-1}·min^{-1}). Activities are shown in order of increasing intensity. Accelerometer counts for lying and sitting are not shown, as these were zero for 88.2% of the lying values and 72.7% of the sitting values. These two activities were excluded from all further analysis.

Derivation of prediction equation

Figure 1 shows the relationship between counts per minute and energy expenditure for each activity for the whole sample. Unadjusted Pearson's correlation coefficients are also shown on each graph. Correlations were highest for the locomotor activities. The unadjusted Pearson's correlation for all activities combined was 0.82; $p < 0.001$.

The developmental group comprised; 73 boys and 90 girls. The validation group comprised 37 boys and 46 girls. The equation to predict energy expenditure from accelerometer counts is:

$$\text{Energy expenditure (kJ}\cdot\text{kg}\cdot\text{min}^{-1}) = -0.933 + 0.000098 \text{ counts per minute} + 0.091 \text{ age (years)} - 0.0422 \text{ gender (male} = 0\text{, female} = 1).$$

(SE for counts per minute 2.56×10^{-6}. $R^2 = 67.3\%$).

Backwards elimination confirmed that both potential confounders (age and gender) were required in the equation. There was only weak evidence (24) of a gender × counts interaction ($p = 0.04$), we therefore followed Kirkwood and Sterne's (p. 466) recommendation that a single model was sufficient to describe the data (25). To validate the equation, limits of

Table III. Mean (standard deviation) accelerometer counts per minute, energy expenditure and VO_2 for each activity (whole sample).

Activity	Lying	Sitting	Slow walking	Brisk walking	Hopscotch	Jogging
N	246	245	244	246	235	226
Speed (kph)	-	-	4.4 (0.7)	5.8 (0.8)	-	9.2 (1.5)
Counts per minute	-	-	2954 (984)	4175 (935)	5863 (1501)	7667 (1598)
Energy expenditure (kJ kg min^{-1})	0.13 (0.03)	0.12 (0.03)	0.37 (0.08)	0.48 (0.10)	0.71 (0.12)	0.96 (0.17)
VO_2 (mL·kg^{-1}·min^{-1})	6.1 (1.4)	6.0 (1.3)	17.7 (3.6)	22.8 (4.5)	34.2 (5.2)	44.9 (7.2)

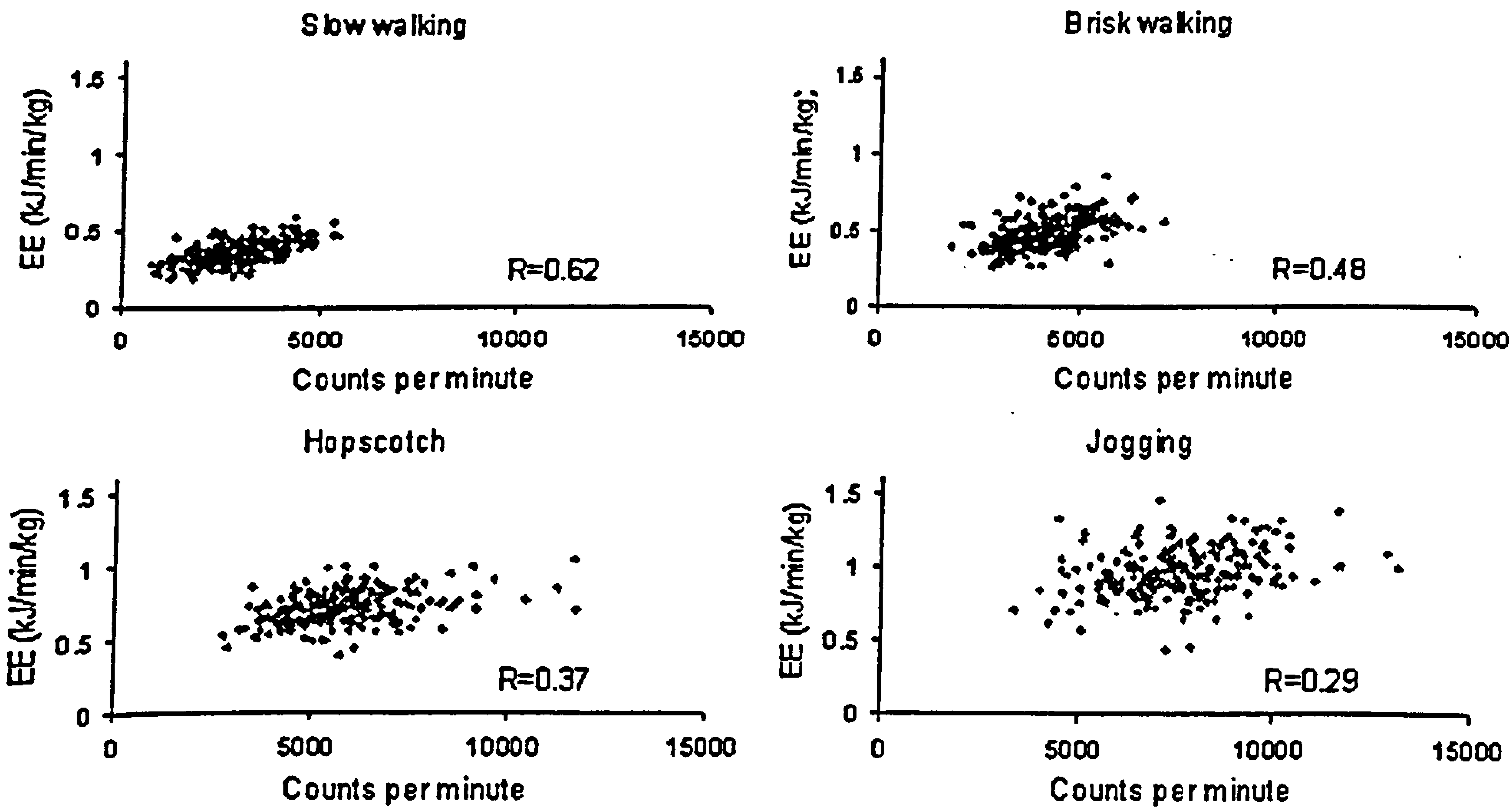

Figure 1. Relationship between counts per minute and energy expenditure for each activity in the whole sample, with Pearson's correlation coefficient shown. All $p < 0.001$. EE = energy expenditure.

agreement were calculated. In the validation group, the mean difference between actual and predicted energy expenditure was -0.01 kJ·kg·min^{-1} and the limits of agreement were -0.28, 0.25. In the developmental group, the mean difference was 0.0 kJ·kg·min^{-1} and the limits of agreement were -0.29, 0.30.

The fit of the prediction equation was checked (normal probability plot of residuals and plot of the residuals against the predicted values; data not shown) and deemed to be adequate. Removing confounding variables one at a time from the equation resulted in the following attenuations of R^2 from 67.3%: age 66.7%; gender 66.2%.

Derivation of activity intensity thresholds

Physical activity intensity cut-points were derived by refitting the prediction equation with VO_2 rather than energy expenditure as the outcome, based on the developmental group (METs are defined as multiples of resting VO_2). The mean resting VO_2 value in the developmental group was 5.7 mL·kg^{-1}·min^{-1} (the minimum of lying or sitting VO_2), which was established as one MET. Table IV shows the lower thresholds for moderate (three and four METs) and vigorous activity (six METs), based on unadjusted and adjusted models. Values are also given for boys and girls separately, adjusting for age. For the cut-points, the adjusted figures were a lower threshold of 3581 counts per minute for moderate activity and 6130 counts per minute for vigorous activity.

For the threshold for moderate activity (four METs), sensitivity was 95.5% and specificity was 60.7%, based on the validation group. Using three METs as the threshold for moderate, sensitivity was 98.2% and specificity was 40.5%. For vigorous activity (six METs) in the same group of children, sensitivity and specificity were 74.1% and 94.7%, respectively.

Discussion

Main findings

In this calibration study we found that Actigraph counts, adjusted for age and gender, could predict energy expenditure across a range of activities. By refitting the model with VO_2 instead of energy

Table IV. Threshold values of counts per minute for moderate and vigorous activity.

METs	Unadjusted – all	Adjusted[a] – all	Adjusted[b] – boys	Adjusted[b] – girls
N	163	163	73	90
3	2323	2306	2184	2389
4	3589	3581	3382	3731
6	6121	6130	5777	6415

[a]Adjusted for age and gender.
[b]Adjusted for age only.

Table V. Comparison of energy expenditure prediction equations from previous studies.

Authors	Population	Study design	Prediction equation	Moderate activity energy expenditure[a] ($kJ \cdot kg^{-1} \cdot min^{-1}$)
Trost et al. (10)	30 children aged 10–14	Laboratory-based. Oxygen uptake as criterion measure. 3 activities	EE ($kcal \cdot min^{-1}$) = −2.23+ 0.0008 cpm+0.08 weight (kg)	0.444
Puyau et al. (9)	26 children aged 6–16	Laboratory and field-based. Oxygen uptake as criterion measure. 9 activities	EE ($kcal \cdot kg^{-1} \cdot min^{-1}$) = 0.0654−0.00197 age+ 0.00001cpm[b]	0.346
Schmitz et al. (8)	74 girls aged 13–14	Field-based. Oxygen uptake as criterion measure. 10 activities	EE ($kJ \cdot min^{-1}$) = 7.6628+0.1462 [(cpm−3000)/100]+0.2371 weight (kg) −0.00216 $[(cpm-3000)/100]^2$+0.004077 [((cpm−3000)/100)weight (kg)]	0.500
Current study	246 children aged 12	Field-based. Oxygen uptake as criterion measure. 4 activities	EE ($kJ \cdot min^{-1} \cdot kg^{-1}$) = −0.933+ 0.000098 cpm+0.091 age (years) −0.0422 gender (male = 0, female = 1)	0.562

EE = energy expenditure, cpm = counts per minute.
[a]Based on "average" girl from the current study. Aged 12.4 years, BMI 18.9, Height 150.6 cm, weight 42.3 kg, accelerometer counts per minute 4175. Values converted to $kJ \cdot kg^{-1} \cdot min^{-1}$.
[b]This equation is different from the original published equation. An erratum has been published (27).

expenditure as the outcome, cut-points for moderate and vigorous activity were derived. Our cut-point for MVPA is higher than the commonly used Trost et al. (15) cut-point, although recent studies have suggested that a higher cut-point may be more appropriate (see Table VI). In previously conducted validity studies, energy expenditure prediction equations and cut-points have varied (see Tables V and VI) (26), raising the possibility of inaccurate estimates of energy expenditure or misclassification into categories of physical activity intensity e.g., MVPA.

This is the first validity study of the Actigraph we are aware of that has derived an energy expenditure equation and developed cut-points specifically in children of this age. It is also the largest study that we are aware of, ensuring that it was adequately powered. Further, the use of self-paced, "free-living" activities may better reflect the ways in which children perform activities in the real world and may to some extent account for differences in fitness between individuals.

Comparison with other studies

Several studies have developed prediction equations or defined cut-points for activity intensity thresholds in children, though study populations, sample sizes and study protocols have varied. Reported R^2 values of 75% (9), 61% (6), 83% (10), 50% (for physical activity energy expenditure i.e., energy expenditure during activity-resting energy expenditure) (14) and a model concordance correlation coefficient of 85% (8) are similar to this study (R^2 67.3%). The inclusion of age and gender made only modest contributions to the overall R^2 in the model. Table V compares energy expenditure prediction equations for an "average" child from this study working at the mean Actigraph counts per minute for moderate physical activity in this study of 4175 counts per minute. As can be seen, there is a wide range in energy expenditure predicted for this child. Some studies have included weight (8,10) and age (9) as covariates in their equations. Differences in study populations and also in study design, including type of activities undertaken, may have contributed to the differences in energy expenditure predicted from previous equations.

Current guidelines recommend that children do at least 60 minutes of moderate to vigorous physical activity (MVPA) per day (28). Interpretation of Actigraph data to assess whether guidelines are being met relies on accurately placed cut-points. Several groups have conducted studies to estimate cut-points for sedentary, light, moderate or vigorous physical activity in children. These are summarised in Table VI for comparison with the present study.

Four of the studies in Table VI (7, 9,15) used VO_2 as the criterion for deriving cut-points. Two (12,13) used direct observation as the criterion measure. Previous studies have categorised activity intensity in different ways. Puyau et al. used energy expenditure ($kcal \cdot kg \cdot min^{-1}$) (9); Trost et al. used energy expenditure (METs) (15); whereas Treuth et al. (7), Sirard et al. (12) and Reilly et al. (13) categorised activities *a priori* e.g., brisk walking (3.5 mph) was defined as moderate (7). Differences in defining categories of physical activity intensity, sample-size, study protocol and characteristics of the study

Table VI. Activity intensity thresholds of previous studies compared with this study.

Authors	Population	Epoch time		Criterion for intensity	Activity intensity	Threshold counts
Puyau et al. (9)	26 children aged 6–16	1 minute		<0.015[b]	sedentary	0–800
				≥0.015	light	801–3200
				<0.05	moderate	3201–8200
				≥0.10	vigorous	>8200
Trost et al.[a] (15)	80 children aged 6–18	1 minute		≥3 METs	moderate	>1267
				≥6 METs	vigorous	≥4057
Reilly[c] et al. (13)	82 children aged 3–4	1 minute		*a priori* categorisation	sedentary	<1100
Treuth et al. (7)	74 girls aged 13–15	30s		*a priori* categorisation	sedentary	0–100
					light	101–2999
					moderate	3000–5200
					vigorous	>5200
Sirard[c] et al. (12)	3 groups of children aged 3, 4 and 5	15s	Age 3 n = 74	*a priori* categorisation	sedentary	0–1204
					light	1205–2456
					moderate	2457–4920
					vigorous	>4920
			Age 4 n = 130	*a priori* categorisation	sedentary	0–1452
					light	1453–3244
					moderate	3245–4936
					vigorous	>4936
			Age 5 n = 81	*a priori* categorisation	sedentary	0–1592
					light	1593–3560
					moderate	3561–5016
					vigorous	>5016
Current study	246 children aged 12	1 minute		≥3 METs	moderate	2306
				≥4 METs	moderate	3581
				≥6 METs	vigorous	6130

Threshold counts reported as counts per minute for comparison and rounded where appropriate.
[a]Based on the mean age of the current study.[b]$kcal \cdot kg \cdot min^{-1}$.
All studies used oxygen uptake as the criterion measure except[c], which were based on direct observation.

population may account for the differences in cut-points seen. Changes in body composition, stride pattern, oxygen uptake kinetics and efficiency of movement as children mature make it unlikely that one set of cut-points or prediction equation will be generalisable for all ages. A "suite" of equations, each suitable for a particular age group, may be the most appropriate way to address these issues of maturation and development in children. An alternative method of accounting for differences in body size and movement efficiency is to use the activity-related time equivalent based on accelerometry (Arte*ACC*), which is calculated as Arte*ACC* = total daily activity counts/reference exercise counts per minute (29). However, Ekelund et al. suggest that high interindividual variability observed during treadmill walking (the reference exercise), indicated the need for individual calibration (29). This may preclude the use of this index in large studies.

Limitations of the study

Practical considerations prevented inclusion of more activities in this study. It could be argued that the use of largely locomotor activities, where vertical movement at the hip is paramount, do not wholly reflect the activities of daily living that children do. For example, no activities that required mainly arm movements were included, although Sleap and Warburton found that children's activities largely consisted of locomotor activities, such as soccer and brisk walking (21). In adults, equations derived to predict energy expenditure from walking activities perform less well when applied to common household activities, such as window washing (30). Activities in this study were performed on a level track whereas children's activity in the real world would include walking or running on inclines where the Actigraph is known to perform less well (14). The activities performed by the children may represent the type of movement that the Actigraph measures better than others. The Actigraph has been reported to underestimate energy expenditure at high running speeds in adults (31) and activities that involved high running speeds were not included in this study. This may result in time spent in vigorous activity being underestimated by our equation. Though time spent in vigorous activity may only represent a small proportion of total activity time, it may represent a higher proportion of total activity. Bailey et al. reported that children aged 6–10 years only spend 3.1% of their time in "high intensity" activity in bouts lasting a median of 3 seconds (32) while Baquet et al. reported that pre-pubertal children spend 2.4% of their time in vigorous and very high intensity physical activity and that this accounted for 36.1% of their total physical activity (33).

This study did not attempt to define a threshold for sedentary behaviour. It has been argued that sedentary behaviour constitutes a health behaviour that is independent of physical activity (34). Although other studies have defined cut-points for sedentary behaviour in children and adolescents of different ages, these have varied considerably by age (7,13). More studies need to be carried out to define sedentary behaviour across a range of ages in order to better examine the health consequences of sedentary behaviour in children.

The mean difference and limits of agreement between actual and estimated energy expenditure (-0.01 kJ·kg·min^{-1}; -0.28, 0.25) suggest that the prediction equation may be imprecise when used on an individual level rather than at group level. However, this is in line with other studies, for example Reilly et al. report that energy expenditure prediction equations may only be suitable for use at group level (16).

The VO_2 values used for resting energy expenditure were not collected using a standard protocol. The measurement period was five minutes whereas a 15-minute protocol is commonly used (19). However, our mean resting VO_2 was 5.7 mL·kg^{-1}·min^{-1} in the developmental group which is comparable with that reported for children of a similar age in the study of Harrell et al. (19). We used the final minute of each five-minute activity in order to allow VO_2 to stabilise after the previous activity so that the VO_2 accurately reflected the energy expenditure of each activity. Children's activities are often not sustained and it may therefore be that steady state means, such as these, apply less well in free-living children.

Summary

This study has developed an equation for predicting energy expenditure from accelerometer counts in a large group of adolescent children utilising a variety of self-paced activities commonly performed by children. Intensity cut-points for moderate and vigorous activity were also derived. Potential confounding by age and gender has been accounted for. We have demonstrated that reasonable estimations of energy expenditure can be made utilising accelerometer data together with other easy to measure variables. We also defined cut-points for moderate and vigorous activity that will be of use in studies of children from a similar age group.

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Appendix 3

Intraindividual Variation of Objectively Measured Physical Activity in Children

CALUM MATTOCKS[1], SAM LEARY[1], ANDY NESS[4], KEVIN DEERE[1], JOANNE SAUNDERS[1], JOANNE KIRKBY[2], STEVEN N. BLAIR[3], KATE TILLING[1], and CHRIS RIDDOCH[5]

[1]*Department of Social Medicine, University of Bristol, UNITED KINGDOM;* [2]*Institute of Diet, Exercise and Lifestyle University of Glasgow, Glasgow, UNITED KINGDOM;* [3]*University of South Carolina, Columbia, SC;* [4]*Department of Oral and Dental Science, University of Bristol, UNITED KINGDOM;* [5]*Department of Sport and Exercise Science, School for Health, University of Bath, UNITED KINGDOM*

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ABSTRACT

MATTOCKS, C., S. LEARY, A. NESS, K. DEERE, J. SAUNDERS, J. KIRKBY, S. N. BLAIR, K. TILLING, AND C. RIDDOCH. Intraindividual Variation of Objectively Measured Physical Activity in Children. *Med. Sci. Sports Exerc.*, Vol. 39, No. 4, pp. 622–629, 2007. **Purpose:** This study examined the seasonal and intraindividual variation in objectively measured physical activity in 11- to 12-yr-olds. **Methods:** Children were asked to wear a uniaxial accelerometer for 7 d four times throughout the course of about a year. A random-intercepts model was used to separate the inter- and intraindividual components of physical activity. Gender, age, body mass index (BMI), height, and month of measurement were fitted to the model as potential confounders. **Results:** A total of 315 children had valid data for at least two measurement occasions, and 244 had data for all four measurement occasions. The unadjusted intraclass correlation coefficient (ICC) for total activity (counts per minute) was 0.54; 0.49 after adjusting for gender, age, and BMI; and 0.53 after adjusting for gender, age, BMI, and month. Further adjustment for pubertal status at baseline had no effect on the ICC. Restricting the analysis to only those with data for all four measurement occasions ($N = 244$), or to measurements taken on schooldays only, had no effect on the ICC. The fully adjusted ICC was 0.51 for weekdays only and 0.39 for weekend days only. For minutes of moderate to vigorous physical activity, minutes of vigorous activity, minutes of sedentary behavior, and number of 30-min blocks of sedentary behavior, the fully adjusted ICC were 0.45, 0.37, 0.59, and 0.39, respectively. The analysis was repeated for boys and girls separately, but the differences in ICC were small. **Conclusion:** There was substantial intraindividual variation in the objectively measured physical activity of these children. Studies using single a measurement occasion where physical activity is the exposure should take this into account to adjust for regression dilution. **Key Words:** RELIABILITY, VARIABILITY, MEASUREMENT ERROR, SEASONALITY, ALSPAC

Physical activity in children is thought to be beneficial for health, with current guidelines recommending that children achieve 60 min or more of at least moderate physical activity each day (18). Assessing habitual physical activity in children is difficult because their activities tend to be sporadic in nature and of short duration (1), and they find it more difficult than adults to accurately recall activity. This means that self-report methods, such as questionnaires, are impractical in children because they are likely to be inaccurate (11). Objective measures overcome some of the problems of measuring physical activity in children; as a result, accelerometry-based physical activity monitors have become increasingly popular as a means of assessing physical activity in children (26).

Most studies rely on a single period of measurement to characterize habitual physical activity in children, that is, the average level of physical activity over time. This specified period is typically between 3 and 7 d, with 3–4 d of valid recording considered the minimum needed to characterize habitual physical activity (17,24). These estimates of the required number of days are based on studies that use single periods of measurement rather than repeated measurements over time. Typically, studies have estimated the number of consecutive days of measurement needed to achieve a reliability coefficient of 0.8 (24). Habitual physical activity has been shown to vary over time and by season in adults (12,15) and by season in children (2,5). It is likely that physical activity levels in children change over time and that physical activity varies by season and according to whether the child is measured while at school or while on holiday. It is, therefore, possible that current studies have overestimated the precision of objective measurement in children by relying on a single period of measurement that may not represent habitual physical activity (12).

Measurement error (which includes error from imperfect instruments and intraindividual variation) in exposure

Address for correspondence: Calum Mattocks, Department of Social Medicine, University of Bristol, 24 Tyndall Avenue, Bristol, BS8 1TQ United Kingdom; E-mail: c.mattocks@bristol.ac.uk.
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variables leads to the phenomenon of regression dilution bias. Where this occurs, the regression coefficient quantifying the relationship between the exposure and the outcome (e.g., physical activity and obesity) is attenuated (10). Where repeated measurements of the exposure have been collected, the intraclass correlation coefficient (ICC; the ratio of interindividual variance to total variance) can be estimated and used to adjust the regression coefficient (10). Though this correction probably yields a better estimate than the unadjusted coefficient, it may overestimate the regression coefficient because it assumes all observed variation in measurements over time is attributable to measurement error.

In this paper, we describe a large study of repeated accelerometer measurements in children for a full calendar year, with ICC estimated for a range of physical activity summary measures. We hypothesized that there would be substantial intraindividual variation in children's physical activity over the study period, and we used the ICC obtained in this study to estimate this variation. The ICC will be used to correct the estimates for regression dilution bias found in our own study of the associations between objectively measured physical activity and obesity, and it will be useful in other studies for correcting estimates for regression dilution bias.

METHODS

Children were recruited from the Avon Longitudinal Study of Parents and Children (ALSPAC). This is an ongoing, geographically based birth cohort that has been described in detail elsewhere (7) (http://www.alspac.bris.ac.uk). Briefly, pregnant women living in one of three Bristol-based health districts with an expected delivery date between April 1991 and December 1992 were invited to take part; 14,541 of them accepted. These pregnancies resulted in 14,062 live births, of which 13,988 babies were alive at 12 months. Mothers, partners, and children have been sent regular questionnaires since they were enrolled. All the children were invited to a detailed hands-on clinical assessment annually from ages 7 to 11. Ethical approval was obtained from the ALSPAC law and ethics committee and local research ethics committees.

Socioeconomic status (SES) by occupation was recorded by questionnaire during pregnancy in all ALSPAC children. Categories were combined into manual and nonmanual categories to create a dichotomous variable. These data were used for descriptive purposes in the study.

At the 11-yr clinic, height was measured to the nearest millimeter with a Harpenden Stadiometer (Holtain Ltd, Crosswell, UK). Weight was measured to the nearest 50 g with a Tanita body fat analyzer and weighing scale (Model TBF 305, Tanita UK Ltd Middlesex, UK). Body mass index (BMI) was calculated by dividing weight (kg) by squared height (m^2). Data on body size were only collected at baseline. After the initial contact, the accelerometers were mailed to the children and were returned by mail.

Pubertal status was derived from a Tanner stage questionnaire (20), and analysis was restricted to those who completed it within 16 wk of the baseline measure. Girls were classified according to Tanner stage on the basis of most advanced breast and pubic hair development, and boys were classified on the basis of pubic hair development alone.

Children were asked to wear an Actigraph AM7164 accelerometer (Actigraph, LLC, Fort Walton Beach, FL) for 7 d as part of a study of physical activity and obesity. The Actigraph accelerometer is a uniaxial accelerometer that uses a piezoelectric lever to detect acceleration ranging from 0.05 to 2.13*g*. As the subject moves, the lever bends and a signal is generated in proportion to the amount of acceleration; thus, intensity of movement is recorded. The signal is sampled 10 times per second, and the values are summed for a user-specified epoch (25). One-minute epochs are generally used in field studies, allowing approximately 22 d of recording. One-minute epochs were used in the current study. The internal clock in the Actigraph allows time and duration as well as intensity of physical activity to be monitored; thus, daily patterns of physical activity can be described (26).

All children who attended the 11-yr clinic were asked to wear the Actigraph for 7 d during waking hours and to only take it off for showering, bathing, or any water sports. Each child was asked to wear the Actigraph on the right hip attached with an elastic belt. Actigraphs were initialized for each clinic using an Actigraph Reader Interface Unit RIU-41A with RIU software (Version 2.26B, Actigraph, LLC, Fort Walton Beach, FL) connected to a PC. All Actigraphs were initialized to start recording at 5:00 a.m. on the day after each child's clinic visit. Returned Actigraphs were downloaded onto a PC using the Actigraph Reader Interface Unit and software described above. The raw data were then imported using customized software, which imported the data into a Microsoft Access 2000 database and derived a series of variables: counts per minute (as a measure of total activity), minutes spent in moderate to vigorous physical activity (MVPA), minutes of sedentary behavior, and blocks of sedentary behavior longer than 30 min. The software automatically deleted blocks of 10 or more consecutive zeros to account for periods of nonwear. This is in line with the European Youth Heart Study (18). Cut points for moderate and vigorous physical activity ($\geq$ 3600 and $\geq$ 6200 counts per minute, respectively) were derived from our calibration study of 246 children, where Actigraph counts per minute were compared against oxygen uptake. The sedentary cut point was similar to that used by Treuth et al. (21), who defined sedentary as < 50 counts per 30 s. The software used in this study derived categories of physical activity intensity in blocks of 200 counts per minute; sedentary was defined as 0–199 counts per minute.

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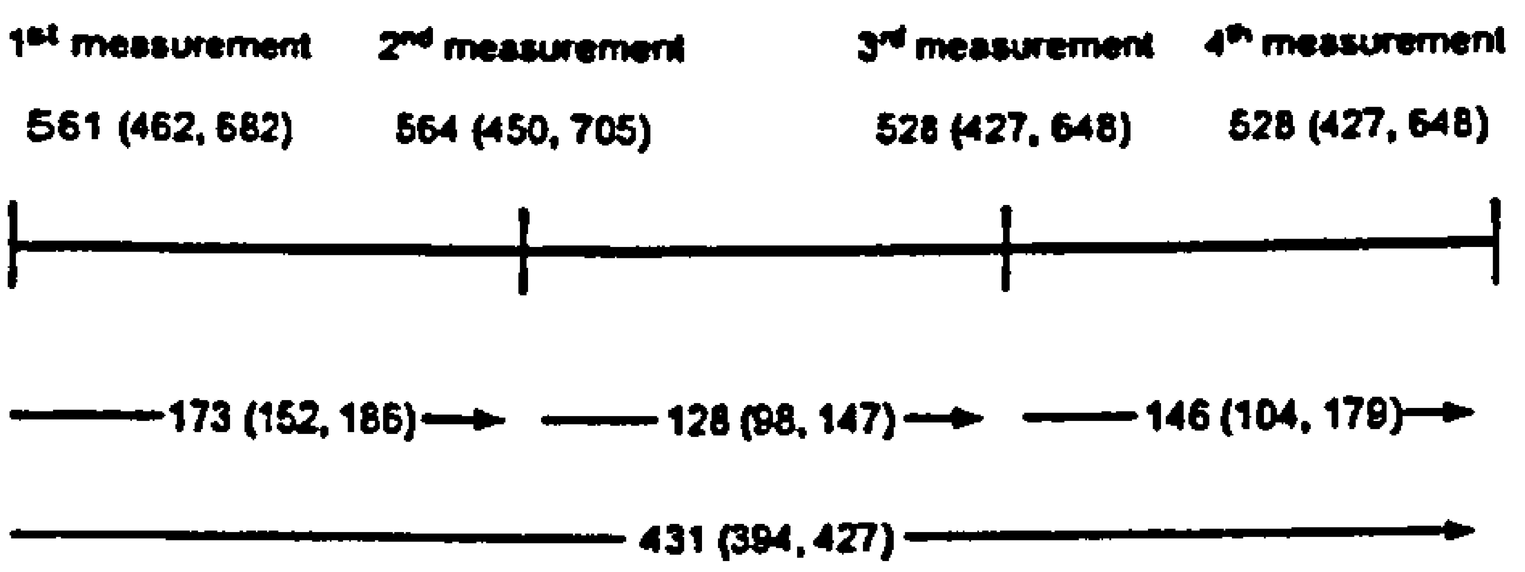

FIGURE 1—Timeline of measurement occasions with geometric mean (IQR) for counts per minute and median (IQR) number of days between measurements.

The children who came to the 11-yr ALSPAC clinic were asked whether they would be willing to take part in one of three unspecified substudies. Of those who were willing to take part in a substudy (N = 1595) and who had successfully worn the Actigraph on the initial occasion, 548 were randomly selected for inclusion in this study. Participants were contacted approximately 3 months after the first occasion of wearing the Actigraph, and a date was agreed on for them to wear it again for 7 d. The Actigraph, along with instructions, a return envelope, and a timesheet to record when the Actigraph was put on and taken off, were mailed to them. This was repeated twice more so that children wore the Actigraph a total of four times during the course of a year in each season.

Statistical analyses. Statistical analyses were carried out using Stata Version 8.0 for Windows (Stata Corporation, College Station, TX). The main outcome measure was counts per minute, which has previously been validated against doubly labeled water (4). Additional outcomes examined were weekday and weekend counts per minute, minutes of MVPA, minutes of vigorous physical activity, minutes of sedentary behavior, and blocks of sedentary behavior lasting 30 min or more. All outcome variables had skewed distributions, so log transformations were used.

t-tests and tests for proportion were used to test for differences between the characteristics of participants and those attending the ALSPAC 11-yr clinic. A random-intercepts model was fitted with logged counts per minute as the outcome, based on data from up to four measurement occasions per child. The ICC was calculated from this because the aim was to estimate variation over a year (12), not variation within a single measurement occasion (24). Initially, the model was fitted with no fixed effects. Then, a forward stepwise procedure was used to decide which of the possible confounders (gender, height, BMI, and age) were required. The selected variables were centered before being added to the model as fixed effects, to allow calculation of predicted mean values. Finally, month of measurement was also added to the model. Because the relationship between logged counts per minute and month was not linear, sine and cosine functions of month were included as fixed effects in the model. Models containing different numbers of sine and cosine functions were compared to see which best fitted the data. For each of the three models (unadjusted, adjusted for potential confounders, and adjusted for potential confounders plus functions of month) with logged counts per minute as the outcome, the mean, intraindividual standard deviation (SD), coefficient of variation (CV; SD as a percentage of the mean), and ICC were calculated. As a log scale was used, the CV was calculated by taking the antilog of the intraindividual SD and subtracting one.

The main analysis was carried out for boys and girls, both combined and separately. The analyses were repeated with baseline pubertal status added to the final model. Analyses were also repeated with the measurement occasion excluded if any swimming and/or cycling were reported on that occasion (the Actigraph does not measure cycling activity well, and swimming was chosen as a typical pursuit that would result in unrecorded physical activity). Analyses were repeated with weekdays of monitoring while the child was on school holidays excluded and, finally, by restricting to children with data for all four measurement occasions only. The analyses for counts per minute and minutes of MVPA were repeated restricting the number of valid days on each measurement occasion to 3, 4, or 5 d, and 6 or 7 d combined, for children with data for all four seasons. Days 6 and 7 were combined because of low numbers, so the maximum of either 6 or 7 d was used. Thus, combinations of 6 and 7 d across four seasons were possible.

RESULTS

Of the 548 children who were contacted, 349 (64%) agreed to participate in the study. Of those who agreed to

TABLE 1. Comparison of characteristics between study sample and ALSPAC 11-yr clinic.

	All		Boys		Girls	
	Current Study	11-yr Clinic	Current Study	11-yr Clinic	Current Study	11-yr Clinic
	(N = 315)	(N = 6844)	(N = 148)	(N = 3370)	(N = 167)	(N = 3474)
Age (yr)[a]	11.65‡ (0.19)	11.79 (0.24)	11.64‖ (0.18)	11.78 (0.24)	11.67¶ (0.21)	11.79 (0.24)
BMI (kg·m^{-2})[b]	18.2 (16.4, 20.7)	18.3 (16.6, 20.9)	17.7 (16.4, 20.2)	18.0 (16.5, 20.6)	18.5 (16.3, 21.0)	18.6 (16.8, 21.3)
Height (cm)[a]	150.0* (7.4)	150.8 (7.3)	148.8† (6.7)	150.1 (7.2)	151.1 (7.8)	151.5 (7.3)
Weight (kg)[b]	41.0 (35.8, 48.6)	41.8 (36.4, 49.4)	40.2 (35.0, 46.0)	40.8 (35.8, 47.8)	41.6 (36.0, 50.0)	43.0 (37.0, 50.6)
Socioeconomic status (% nonmanual)	59.0	56.0	59.6	56.6	58.4	55.4

[a] Mean (SD); [b] median (IQR).
‡ $P < 0.001$ for difference between all in this study and all in 11-yr clinic.
‖ $P < 0.001$ for difference between boys in this study and boys in 11-yr clinic.
¶ $P < 0.001$ for difference between girls in this study and girls in 11-yr clinic.
* $P < 0.05$ for difference between all in this study and all in 11-yr clinic.
† $P < 0.05$ for difference between boys in this study and boys in 11-yr clinic.

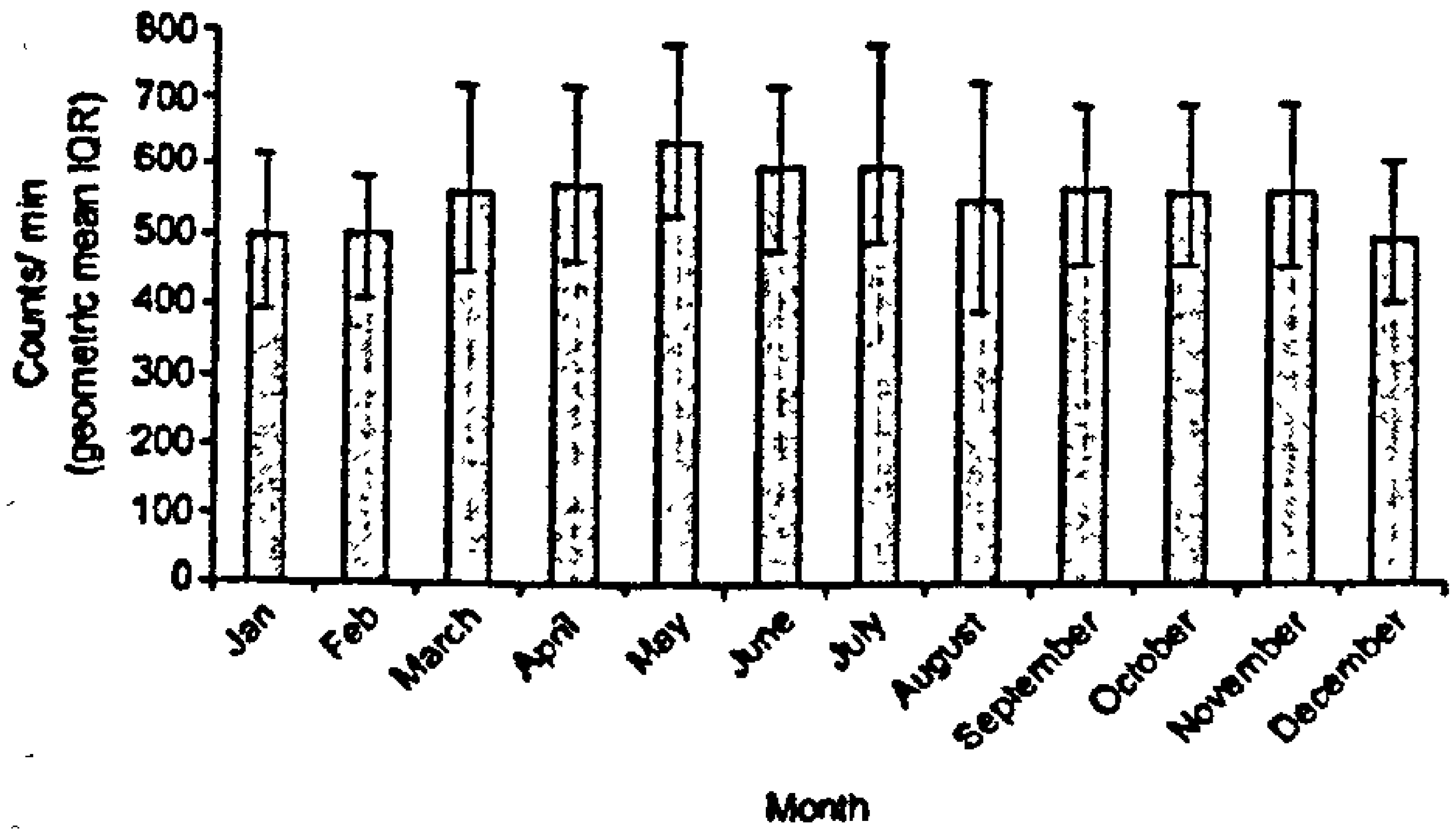

FIGURE 2—Geometric means (IQR) by month of the year.

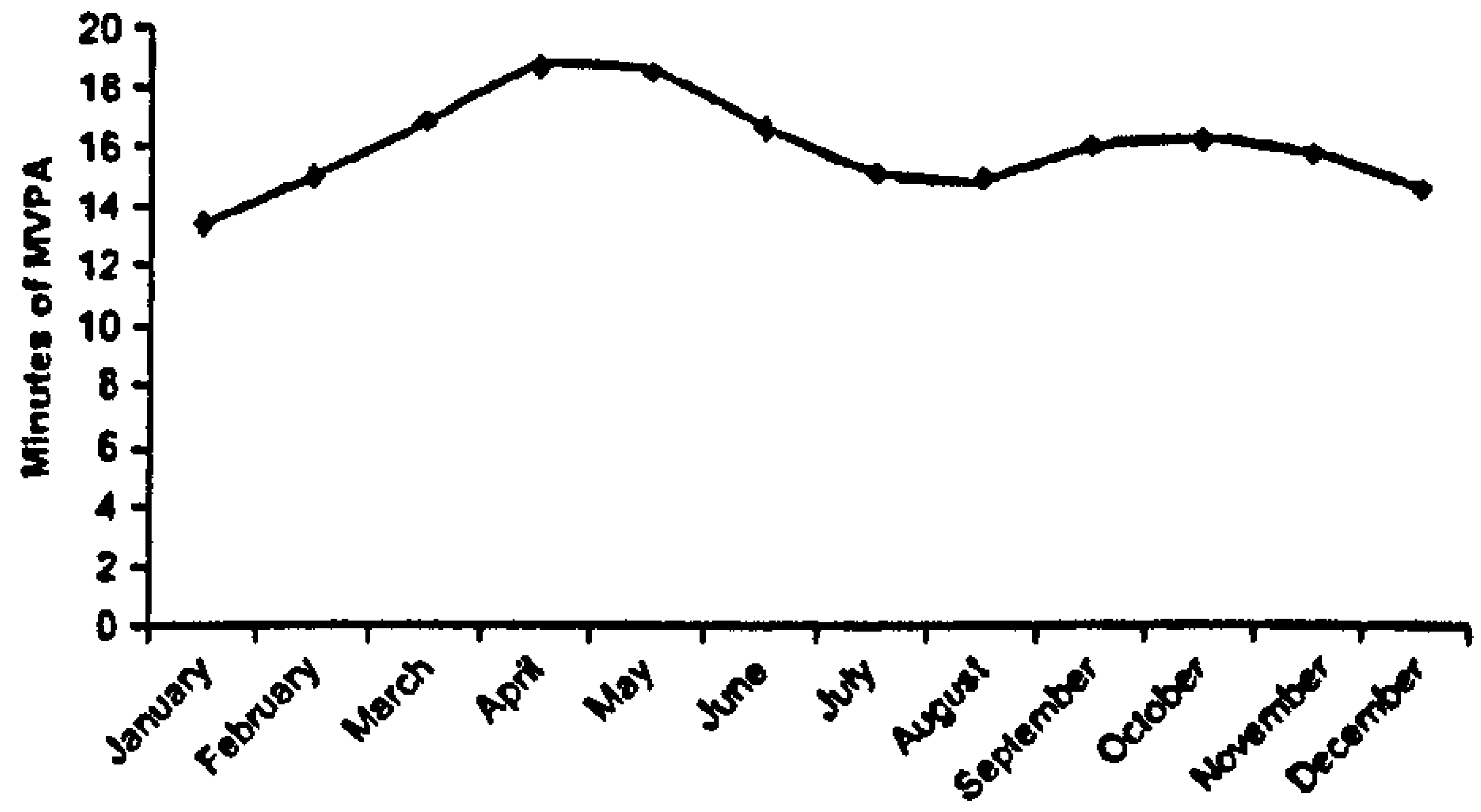

FIGURE 4—Predicted geometric means for MVPA from model with and two sine and cosine functions for month.

participate, 315 (90%) had valid data for season 1, 300 (86%) for season 2, 282 (81%) for season 3, and 273 (78%) for season 4. Two hundred forty-four (70%) children had valid data for all four seasons. Valid data were defined as at least 3 d of measurement of at least 10 $h \cdot d^{-1}$ although the mean (SD) number of hours the monitor was worn per day was 13.1 (0.8). The median (IQR) length of time between each measurement and the geometric mean (IQR) counts per minute at each measurement is shown in Figure 1. The mean valid number of days of measurement for seasons 1–4 were 6.1, 5.8, 5.6, and 5.6, respectively.

Table 1 shows the characteristics of participants compared with all children who attended the 11-yr clinic. Children who participated in our study tended to be younger, shorter, lighter, and from higher socioeconomic backgrounds, although the differences were small, and most P values for the differences were > 0.05.

Figure 2 shows the geometric means for each month of the year with children tending towards lower physical activity in the winter months.

The forward stepwise procedure suggested that gender, age, and BMI should be included as potential confounders. Comparing sine and cosine functions of month of measurement demonstrated that one sine and one cosine function were required for most of the summary measures, thus allowing one peak and one trough within the year. Minutes of MVPA required two sine and two cosine functions to account for two peaks and two troughs. Figures 3 and 4 show the predicted means for counts per minute and minutes of MVPA fitted with the sine and cosine functions.

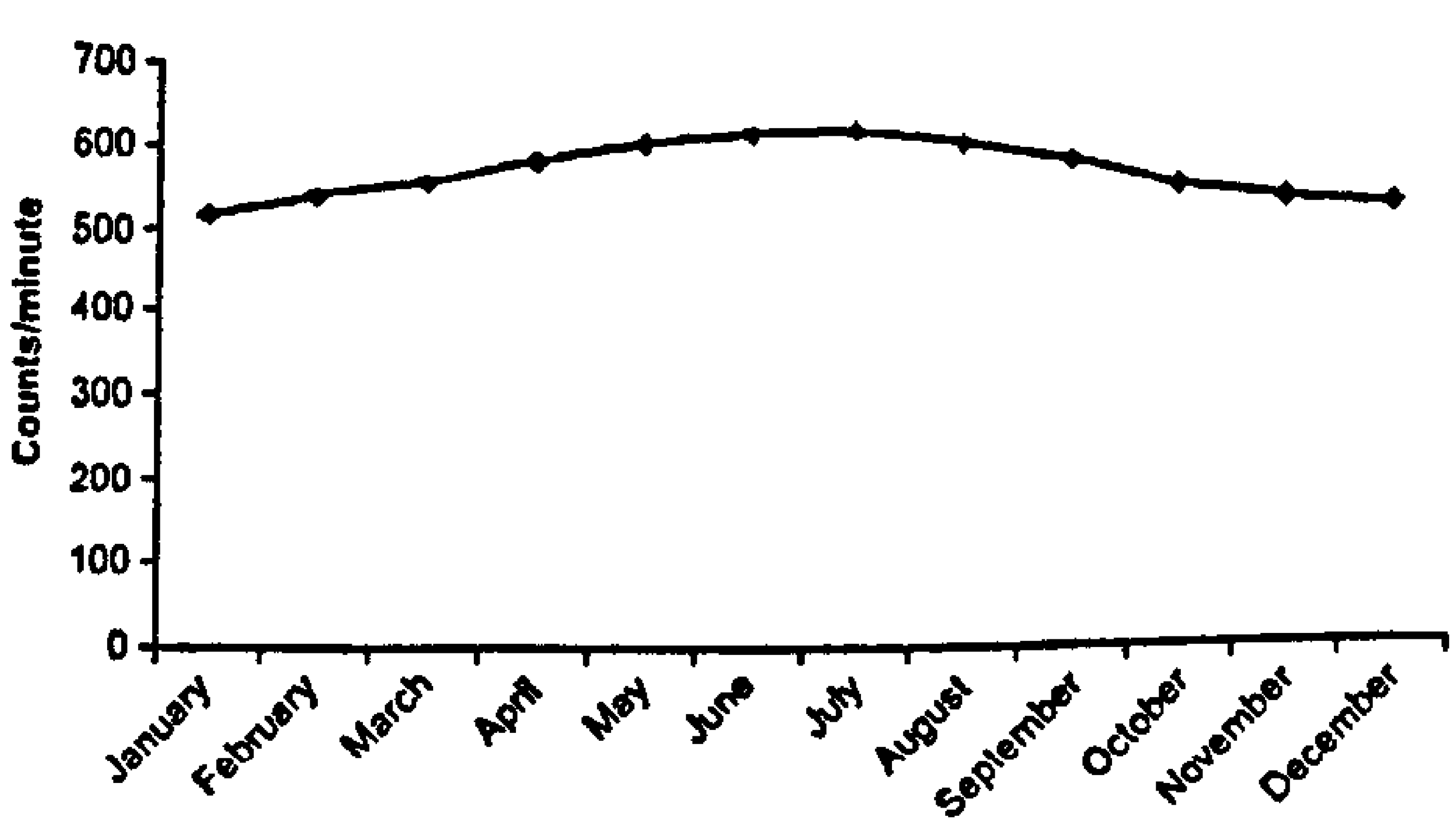

FIGURE 3—Predicted geometric means for counts per minute from model with one sine and cosine function for month.

Table 2 summarizes the unadjusted and adjusted physical activity summary measures, intraindividual standard deviations, CV, and ICC. Adjustment for confounding variables had little effect on these estimates. Table 3 shows the intraindividual standard deviations, CV, and ICC for boys and girls separately. Excluding any measurement occasions on which children reported any swimming or cycling (restricting the analysis to 291 children), the ICC and CV for counts per minute, adjusted for gender, age, BMI, and month were 0.53 and 20.48%, respectively. Excluding weekdays when children were not at school during the measurement period (e.g., during school holidays),

TABLE 2. Intraclass correlation coefficients for physical activity summary measures.

	Unadjusted	Partially Adjusted[a]	Fully Adjusted[b]
Geometric mean (counts per minute)	563	563	567
Intraindividual SD	0.20	0.20	0.19
CV*	22.46%	22.28%	21.30%
ICC**	0.54	0.49	0.53
Geometric mean weekday (counts per minute)	567	567	571
Intraindividual SD	0.21	0.21	0.20
CV*	23.10%	22.97%	21.87%
ICC**	0.54	0.48	0.51
Geometric mean weekend (counts per minute)	518	515	521
Intraindividual SD	0.35	0.35	0.34
CV*	41.94%	41.57%	40.00%
ICC**	0.38	0.39	0.39
Geometric mean minutes MVPA[c]	16.1	16.1	15.9
Intraindividual SD	0.53	0.53	0.53
CV*	70.50%	70.29%	69.27%
ICC**	0.51	0.46	0.45
Geometric mean minutes vigorous activity	2.1	2.1	2.2
Intraindividual SD	0.89	0.89	0.88
CV*	143.50%	143.63%	140.29%
ICC**	0.40	0.36	0.37
Geometric mean minutes sedentary	441	441	440
Intraindividual SD	0.10	0.10	0.10
CV*	10.90%	10.64%	10.22%
ICC**	0.57	0.58	0.59
Geometric mean ≥ 30-min blocks sedentary	0.8	0.8	0.8
Intraindividual SD	0.63	0.61	0.61
CV*	87.64%	85.40%	83.59%
ICC**	0.39	0.39	0.39

* CV = coefficient of variation = SD as percentage of mean.
** ICC = intraclass correlation coefficient = interindividual variance/total variance.
[a] Adjusted for gender, age, BMI; [b] adjusted for gender, age, BMI, and month;
[c] adjusted for month with two sine and two cosine functions.

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TABLE 3. Intraclass correlation coefficients for physical activity summary measures for boys and girls.

	Boys			Girls		
	Unadjusted	Partially Adjusted[a]	Fully Adjusted[b]	Unadjusted	Partially Adjusted[a]	Fully Adjusted[b]
Geometric mean (counts per minute)	622	619	624	515	516	520
Intraindividual SD	0.20	0.20	0.19	0.20	0.20	0.19
CV*	22.66%	22.66%	20.84%	22.28%	21.86%	20.97%
ICC**	0.50	0.48	0.53	0.49	0.50	0.53
Geometric mean weekday (counts per minute)	632	629	635	515	516	518
Intraindividual SD	0.21	0.21	0.19	0.21	0.21	0.20
CV*	22.85%	22.86%	21.11%	23.32%	23.00%	22.39%
ICC**	0.49	0.48	0.53	0.47	0.48	0.49
Geometric mean weekend (counts per minute)	554	549	554	485	486	492
Intraindividual SD	0.37	0.37	0.36	0.33	0.33	0.32
CV*	44.49%	44.36%	42.82%	38.73%	39.34%	37.23%
ICC**	0.37	0.36	0.38	0.39	0.38	0.41
Geometric mean minutes MVPA[c]	20.3	20.1	20.4	13.0	13.0	12.6
Intraindividual SD	0.52	0.52	0.51	0.55	0.54	0.54
CV*	68.01%	68.07%	66.67%	72.74%	72.22%	71.07%
ICC**	0.46	0.44	0.44	0.46	0.46	0.47
Geometric mean minutes vigorous activity	2.8	2.7	2.7	1.7	1.7	1.7
Intraindividual SD	0.91	0.91	0.89	0.87	0.87	0.86
CV*	147.57%	147.61%	144.04%	139.65%	139.52%	136.75%
ICC**	0.31	0.27	0.29	0.41	0.42	0.42
Geometric mean minutes sedentary	430.6	431.8	429.6	449.9	449.6	447.5
Intraindividual SD	0.11	0.10	0.10	0.10	0.10	0.09
CV*	11.15%	10.95%	10.50%	10.66%	10.35%	9.91%
ICC**	0.60	0.61	0.62	0.53	0.54	0.56
Geometric mean ≥ 30-min blocks sedentary	0.8	0.8	0.7	0.9	0.9	0.9
Intraindividual SD	0.63	0.62	0.61	0.63	0.61	0.60
CV*	87.73%	86.12%	84.3%	87.57%	83.37%	82.13%
ICC**	0.37	0.34	0.35	0.40	0.42	0.42

* CV = coefficient of variation = SD as percentage of mean.
** ICC = intraclass correlation coefficient = interindividual variance/total variance.
[a] Adjusted for gender, age, BMI; [b] adjusted for age, BMI, and month; [c] adjusted for month with two sine and two cosine functions.

the ICC and CV, adjusted for gender, age, BMI, and month, were 0.53 and 20.56%, respectively. Finally, restricting to those children with data for all four seasons (244 children), the ICC and CV, adjusted for gender, age, BMI, and month, were 0.53 and 21.01%, respectively. The ICC and CV were similar whether unadjusted or adjusted for gender, age, and BMI. Adding pubertal status at baseline to the final model (restricting the analysis to 215 children with data on pubertal status) had little effect on the ICC. A comparison of the ICC for different numbers of days of measurement on each measurement occasion for counts per minute and minutes of MVPA showed increasing ICC and decreasing variability as number of days included in the model increased (see Table 4). The ICC for 5 and 6 d or 7 d of measurement were similar to the final model in which 3–7 d were used. This is not surprising, because the mean number of days of measurement was 5.9.

TABLE 4. Intraclass correlation coefficients for selected physical activity summary measures for different numbers of days of measurement per occasion.

	3 d	4 d	5 d	6 or 7 d
N[a]	244	215	161	87
Geometric mean[b] (counts per minute)	556	554	557	566
Intraindividual SD	0.23	0.21	0.19	0.18
CV*	25.75%	23.48%	21.26%	19.60%
ICC**	0.45	0.48	0.52	0.56
Geometric mean minutes MVPA[c]	14.8	15.2	15.8	16.7
Intraindividual SD	0.64	0.59	0.54	0.50
CV*	89.29%	80.31%	71.95	64.47%
ICC**	0.38	0.40	0.44	0.46

* CV = coefficient of variation = SD as percentage of mean.
** ICC = intraclass correlation coefficient = interindividual variance/total variance.
[a] Numbers restricted to those with data for all four measurement occasions.
[b] Adjusted for gender, age, BMI, and month; [c] adjusted for gender, age, BMI, and month with two sine and two cosine functions.

DISCUSSION

Main findings. The aim of this study was to estimate the variability of children's physical activity during 1 yr by taking repeat measures and by using the ICC to estimate the effects of month of year. This is the first study we are aware of that has used such a repeat-measures design with an objective method of measuring physical activity in children. The ICC for counts per minute, adjusted for gender, age, BMI, and month, was 0.53, suggesting that there is substantial intraindividual variation in children's physical activity—an ICC of 1.0 would indicate that all the variation is between rather than within children. The small amount of attenuation from 0.54 to 0.49 after adjustment for gender, age, and BMI suggests that these estimates were not markedly affected by these confounding factors. The increase in ICC from 0.49 to 0.53 after adjustment for month of measurement indicates an effect of month of measurement, though not a large one. Although not an *a priori* hypothesis, counts per minute for summer and winter (defined as May, June, July and November, December, January (5)) was 615 and 522 counts per minute, respectively. When the analysis was repeated with pubertal status at baseline included, excluding measurement occasions on which children reported any swimming or cycling, excluding school holidays, or restricting to those who had data for all four measurement occasions, the ICC remained unchanged. This suggests that the estimated ICC of these children's activity was unaffected by the modest amount of swimming and cycling done, whether the children were at school or on holiday or whether they had complete data for all measurement occasions. The ICC for counts per minute for weekdays only was similar to that for the whole measurement period, at 0.51, but was lower for weekends only, at 0.39, suggesting that there was more intraindividual variation on weekends. The ICC for minutes of MVPA, minutes of vigorous physical activity, and blocks of sedentary behavior of at least 30 min all show more intraindividual variation. All ICC remained unchanged or were similar after adjustment for gender, age, BMI, and month. The inclusion of two sine and two cosine functions for MVPA suggests two peaks and two troughs in the data, as indicated in Figure 3. Data also were analyzed separately for boys and girls, though the results were generally similar (Table 3). The size of the ICC (ranging from 0.37 to 0.59 for combined analyses) indicates that there is substantial instability in children's physical activity during 1 yr. The study design allowed us to estimate the ICC—a measure of reliability that can be used to correct for regression dilution, which may occur when an exposure is imprecisely measured, that is, when a single measure is used to estimate the "usual" value of a parameter that may vary over time (10). This can result in underestimation of the regression coefficient, where, for example, physical activity is the exposure and obesity is the outcome. The regression coefficient can be corrected by dividing by the ICC. Because the ICC in this study is 0.53, this would effectively double the regression coefficient in the outcome. However, this assumes that all the variation is intraindividual variation, which may not be the case.

Comparison with other studies. We are not aware of any other studies in children that have estimated variability in physical activity using objective measures during the course of a year. Several studies have estimated the variability for single measurement occasions. Treuth et al. (22) found an ICC of 0.37 in 68 girls aged 8–9 for counts per minute during a 4-d measurement period. In 30 children aged 7–15, Janz et al. (9) observed ICC for counts per minute ranging from 0.75 to 0.78 and 0.81 to 0.84 for 4 and 6 d of monitoring, respectively. For minutes of MVPA, an ICC of 0.42 for 1 d of measurement was reported by Murray et al. (13). Trost et al. (24), studying children and adolescents, found ICC for minutes of MVPA of between 0.64 and 0.79 and between 0.76 and 0.86 (depending on age group) for 4 and 7 d of measurement, respectively. With the exception of Treuth et al. (22), studies that use single measurements generally have higher ICC than those found in this study: 0.53 for counts per minute and 0.45 for minutes of MVPA. This could be attributed to differences in study population. For example, Trost et al. (24) found that the ICC for MVPA was lower (i.e., intraindividual variation was greater) in older children. It also could be affected by whether the children were assessed during term time or while on holiday from school. Or, it could represent genuine intraindividual variability that occurs over longer periods, because it is known that children's physical activity levels decrease as they get older. Differences in MVPA cut points also could account for our relatively low ICC. Trost et al. (24) used a cut point that was about half (depending on age group) (6) that of our cut point of 3600 counts per minute. A lower cut point allows a greater range of potential values from which to calculate the ICC; this, in turn, can increase the magnitude of the ICC (19). Examination of different numbers of days of measurement showed that increasing the number of days increased the reliability. This is not surprising and is consistent with other studies that have reported increases in reliability with increases in the number of days of measurement (9,24). There was still substantial variability across a year, even in children with 6–7 d of valid measurement. Few studies have used a repeated-measures design and an objective measure to estimate the variability of physical activity. Levin et al. (12) measured physical activity in 77 adults using the Caltrac accelerometer worn for 48 h every 26 d for a year. The ICC was 0.42, indicating considerable intraindividual variation during a 1-yr period, and they observed seasonal differences, with more physical activity recorded in the summer months compared with winter. The ICC for total activity in our study, at 0.53, is higher, indicating more stability, although the difference is small. This may be attributable to the lower number of days on each measurement occasion in the Levin et al. (12) study: 2 d versus 3–7 d in our study. Studies have demonstrated a seasonal effect on physical activity similar to our observations. Fisher et al. (5) found that in the United Kingdom, total activity measured by accelerometry was highest in the summer months (May, June, July) among 209 3- to 5-yr-olds. Similar seasonal differences have also been reported using doubly labeled water to assess physical activity level cross-sectionally in children (8) and longitudinally in young adults (16). In both studies, physical activity levels were higher in the summer than in the winter (16). Seasonal differences in physical activity may be attributable to differences in climatic conditions such as temperature rather than the seasons. Baranowski et al. (2) also found seasonal differences in the physical activity of 191 3- to 4-yr-olds in Galveston, TX using direct observation, with children tending to be less active when outside during the summer months and more active during the winter months. This contradictory finding may be attributable to the differences in temperature between the southern United States and the United Kingdom. For example, Fisher et al. (5) reported mean summer and winter temperatures during their study period in Glasgow of 12.8°C and 6.4°C, respectively. During our study, seasonal temperature averages for the geographical region

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were 15.5°C during summer and 5.4°C during winter. The average temperature in Galveston, TX during summer was approximately 28°C and 14°C in winter (2). The variability over time of other cardiovascular risk factors also has been reported. Reliability coefficients have been calculated for serum cholesterol in adult males as ranging from 0.74 to 0.91 for data collected on two occasions 3–10 wk apart (10). The relatively lower values found in our study may be attributable to the relative instability of a complex behavior such as physical activity when compared with a biological measurement such as serum cholesterol.

Limitations. Although the main outcome in this study was total activity in counts per minute, the variability of MVPA was also estimated. This study used 1-min epochs, which are generally used in field studies, because this allows approximately 22 d of recording. Studies of direct observation have shown that 95% of children's physical activity bouts last less than 15 s (1). The use of 1-min epochs may, therefore, have the effect of "diluting" the amount of MVPA and vigorous activity, and this may have had led to an underestimation in the amount of recorded MVPA. It has been suggested that shorter epochs should be used to capture moderate and vigorous activity (14,23). Some of the variation in sedentary behavior may have been caused by variations in the number of hours per day the monitor was worn.. A valid day was a minimum of 10 h, although monitors were worn for an average of 13.1 $h \cdot d^{-1}$; therefore, we feel that the variation in sedentary behavior attributable to day length would be minimal. The children in this study will have matured over the course of the study period and also will have matured at different rates (3). It may be that the development and increasing age of children in the current study had an effect on their physical activity (5). This issue was addressed by controlling for pubertal status at baseline. However, we were not able to control for changes in pubertal status during the study period or changes in height or weight, so we could not explore the impact of any changes on ICC estimates.

CONCLUSIONS

Children's physical activity shows considerable intra-individual variation and seasonal variation when measured four times during a 1-yr period. This suggests that a single measurement occasion may not adequately characterize children's usual physical activity. The estimated ICC we present here can be used to correct for regression dilution to obtain more accurate effects estimates.

We are extremely grateful to all the families who took part in this study, the midwives for their help in recruiting them, and the whole ALSPAC team, which includes interviewers, computer and laboratory technicians, clerical workers, research scientists, volunteers, managers, receptionists, and nurses. The UK Medical Research Council, the Wellcome Trust, and the University of Bristol provide core support for ALSPAC. This publication is the work of the authors, and Calum Mattocks and Andy Ness will serve as guarantors for the contents of this paper. This research was specifically funded by the U.S. National Heart, Lung and Blood Institute (R01 HL071248-01A).

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Appendix 4

Objective measurement of levels and patterns of physical activity

Chris J Riddoch, Calum Mattocks, Kevin Deere, Jo Saunders, Joanne Kirkby, Kate Tilling, Sam D Leary, Steve Blair and Andrew Ness

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ORIGINAL ARTICLE

Objective measurement of levels and patterns of physical activity

Chris J Riddoch, Calum Mattocks, Kevin Deere, Jo Saunders, Jo Kirkby, Kate Tilling, Sam D Leary, Steven N Blair, Andy R Ness

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Objective: To measure the levels and patterns of physical activity, using accelerometers, of 11-year-old children participating in the Avon Longitudinal Study of Parents and Children (ALSPAC).
Design: Cross-sectional analysis.
Setting: ALSPAC is a birth cohort study located in the former county of Avon, in the southwest of England. This study used data collected when the children were 11 years old.
Participants: 5595 children (2662 boys, 2933 girls). The children are the offspring of women recruited to a birth cohort study during 1991–2. The median age (95% CI) of the children is now 11.8 (11.6 to 11.9) years.
Methods: Physical activity was measured over a maximum of 7 consecutive days using the MTI Actigraph accelerometer.
Main outcome measures: Level and pattern of physical activity.
Results: The median physical activity level was 580 counts/min. Boys were more active than girls (median (IQR) 644 (528–772) counts/min vs 529 (444–638) counts/min, respectively). Only 2.5% (95% CI 2.1% to 2.9%) of children (boys 5.1% (95% CI 4.3% to 6.0%), girls 0.4% (95% CI 0.2% to 0.7%) met current internationally recognised recommendations for physical activity. Children were most active in summer and least active in winter (difference = 108 counts/min). Both the mother and partner's education level were inversely associated with activity level (p for trend <0.001 (both mother and partner)). The association was lost for mother's education (p for trend = 0.07) and attenuated for partner's education (p for trend = 0.02), after adjustment for age, sex, season, maternal age and social class.
Conclusions: A large majority of children are insufficiently active, according to current recommended levels for health.

See end of article for authors' affiliations

Correspondence to: Professor Chris Riddoch, Sport and Exercise Science, School for Health, University of Bath, Bath BA2 7AY, UK; cjr27@bath.ac.uk

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Regular physical activity in children is associated with improved health.[1-3] A recent systematic review of the evidence relating physical activity to health concluded that children should spend at least 60 min in moderate to vigorous physical activity (MVPA) each day, in order to promote a broad range of health improvements.[3] Few studies[4-6] worldwide have collected objective physical activity data in large samples of children and we lack population-based objective data describing levels and patterns of children's activity. Nevertheless, physical activity is frequently implicated in the escalating levels of type 2 diabetes[7] and obesity[8-12] in children. We report here on objectively measured physical activity levels and patterns in a large contemporary cohort of 11-year-old children—the Avon Longitudinal Study of Parents and Children (ALSPAC).

PARTICIPANTS AND METHODS

Participants

ALSPAC is a birth cohort study that recruited subjects resident in the former county of Avon in the southwest of England, and has been described in detail elsewhere.[13] A total of 14 541 pregnant women were recruited, resulting in 14 062 live births. We conducted the present study between January 2003 and January 2005, when most of the children were 11 years old. The ALSPAC Law and Ethics Committee and other local research ethics committees approved the study.

Methods

Descriptive data

The 32-week antenatal questionnaire asked the mother to record her highest education level, which was categorised into none/CSE (national school exams at age 16), vocational, O level (national school exams at age 16, higher than CSE), A level (national school exams at age 18) or university degree. She also recorded the occupation of both herself and her partner, which were used to allocate them to social class groups (classes I–V with III split into non-manual and manual) using the 1991 Office of Population Censuses and Surveys.[14] Where the social class of the mother and partner differed, the lower of the two was used in the analysis. We used lowest social class because it has been used in previous analyses on this cohort and gives the most variability within this measure. More recent measures of socioeconomic status have been taken, but at this point they are not coded and entered. A puberty questionnaire was filled in by the child's carer (usually the child's mother) when the child was approximately 11 years old, which included questions on pubertal stage. Pubertal stage for boys was based on pubic hair development, and for girls was based on the most advanced stage for pubic hair and breast development.

Measurement of physical activity

We chose the uni-axial MTI Actigraph accelerometer, model WAM 7164 (Manufacturing Technology Inc, Fort Walton Beach, Florida) to measure physical activity. Objective methods such as accelerometers provide considerably greater precision of measurement, as they overcome children's lack of ability to recall and quantify physical activity. They also allow detailed investigation of patterns of activity on a minute-by-minute basis. This instrument is becoming more widely used in

Abbreviations: ALSPAC, Avon Longitudinal Study of Parents and Children; BMI, body mass index; IOTF, International Task Force; MVPA, moderate to vigorous physical activity physical activity studies and has been shown to compare favourably with other similar instruments.[15] It has also proved to be robust in epidemiological, fieldwork situations. The Actigraph is a lightweight, electronic motion sensor comprising a single plane (vertical) accelerometer. The accelerometers are small (4.5×3.5×1.0 cm) and light (about 43 g) and are worn on an elasticated belt on the right hip. Movement in a vertical plane is detected as a combined function of the frequency and intensity of the movement. Movement counts are averaged over defined epochs and these data are stored in memory and subsequently downloaded to a computer. The Actigraph has been validated in both children and adolescents.[16–21]

Actigraphs were programmed to measure 1-min epochs, and the children were asked to wear the Actigraph during waking hours for 7 consecutive days. Although shorter epochs have been recommended—as longer epochs underestimate moderate and vigorous activity, we needed to use 1-min epochs to achieve a full 7 days of measurement. The limiting factor was the data storage capacity of the instrument we used. We accept that a small amount of underestimation of MVPA is inherent in this analysis. Children who did not achieve a minimum of 600 min valid data on at least 3 separate days were omitted from the analyses.[5] We have recently reported[22] data investigating different combinations of minimum day length, minimum days recorded and the influence of weekday and weekend days. Three days of at least 600 min a day recorded gave adequate reliability and power (>90%) and ensured a sufficient sample size for all analyses, irrespective of the inclusion of a weekend day. Although a weekend day was not specified in order to fulfil validity criteria, 90% of children had at least one weekend day of recording.

Two main physical activity variables were derived—total physical activity and time spent in MVPA. Total physical activity was the average accelerometer counts/min over the full period of valid recording. MVPA was the average minutes of moderate and vigorous physical activity per valid day. From our calibration study, the level of accelerometer counts/min corresponding to the lower threshold of moderate intensity activity (4 METS)—assessed by indirect calorimetry—was established as 3600 counts/min. This threshold lies around midway between a "comfortable" walking pace for children (4.4 kmph; 2950 counts/min) and a "brisk" walking pace (5.8 kmph; 4175 counts/min). We additionally derived minutes of activity during individual hours of the day and sustained bouts per day of MVPA lasting at least 5, 10 and 20 min.

Statistical analyses

We analysed the data using Stata version 8.1. The median and the interquartile range (IQR) were calculated for all variables. All physical activity variables, weight and body mass index (body mass index) were skewed, and therefore log transformations were carried out. Statistical tests were carried out on these transformed variables. Differences between groups were assessed using independent samples t tests. A two-sample proportion test was used to test for group differences (participants vs non-participants, boys vs girls) in the proportions of children achieving recommended levels of activity. The total time (min) of MVPA recorded was divided by the number of valid days recording, giving an average number of min/day across the measurement period. We considered this to be more valid than scrutinising each individual day as this would disadvantage children who achieved well in excess of 60 min on 1 day followed by a marginal failure to achieve 60 min on another. The additional activity on day 1 in our view more than compensates (in health terms) for the marginal failure to gain 60 min on the next day.

To establish whether there were differences in activity levels between children with different numbers of days of measurement, mean values of activity counts/min were calculated separately for children with 3, 4, 5, 6 and 7 days of valid activity measurements. Differences between the groups with different numbers of valid days of measurement were assessed using one way analysis of variance (ANOVA). The influence of season and social position on physical activity levels was assessed using multiple linear regression. For the regression analysis, data were not transformed but robust standard errors were used. Robust standard errors allow derivation of confidence intervals and standard errors based on the actual distribution of the outcome variable in the dataset, rather than on an assumed underlying probability distribution.[23]

To use International Task Force (IOTF) criteria, linear regression was used to adjust heights and weights to age 11.5, based on decimal age of each child. BMI was then recalculated from the age-adjusted variables. The IOTF sex-specific cut-offs for age 11.5 were applied.[24] To use the British 1990 criteria, age-specific and sex-specific centiles were used to

Table 1 Physical characteristics and main physical activity variables

	All n=5595	Boys n=2662	Girls n=2933	p Value
Age (years)	11.8 (11.6–11.9)	11.7 (11.6–11.9)	11.8 (11.6–11.9)	NS
Height (cm)	150.5 (145.7–155.4)	149.6 (144.9–154.6)	151.3 (146.3–156.2)	<0.001
Weight (kg)	41.6 (36.2–49.0)	40.4 (35.6–47.2)	42.8 (37.0–50.4)	<0.001
BMI (kg/m²)	18.7 (16.6–20.7)	18.5 (6.4–20.4)	19.0 (16.7–21.1)	<0.001
Overall activity (counts/min)	580 (474–710)	644 (528–772)	529 (444–638)	<0.001
Physical activity weekdays (counts/min)	579 (475–715)	644 (533–784)	529 (445–635)	<0.001
Physical activity weekend (counts/min)	548 (413–723)	599 (443–791)	510 (390–656)	<0.001
Sedentary activity* (min/day)	430 (384–474)	420 (373–464)	440 (394–482)	<0.001
Light activity* (min/day)	322 (284–362)	330 (291–371)	315 (278–353)	<0.001
Moderate activity* (min/day)	17 (10–27)	22 (14–33)	13 (8–21)	<0.001
Vigorous activity* (min/day)	2 (1–4)	3 (1–5)	2 (1–3)	<0.001
MVPA (min/day)	20 (12–31)	25 (16–38)	16 (10–25)	<0.001
Proportion of children meeting recommended activity level† (%, 95% CI)	2.5 (2.1 to 2.9)	5.1 (4.3 to 6.0)	0.4 (0.2 to 0.7)	<0.001

BMI, body mass index; MVPA, moderate to vigorous physical activity.
Data are median and interquartile range (IQR) unless otherwise stated.
p Values relate to sex differences.
Small discrepancies in totals are due to rounding errors.
*Cutpoints used: sedentary = <200; light = 200–3599; moderate = 3600–6199; vigorous = 6200+.
†Recommended activity level ≥60 min of MVPA activity daily.

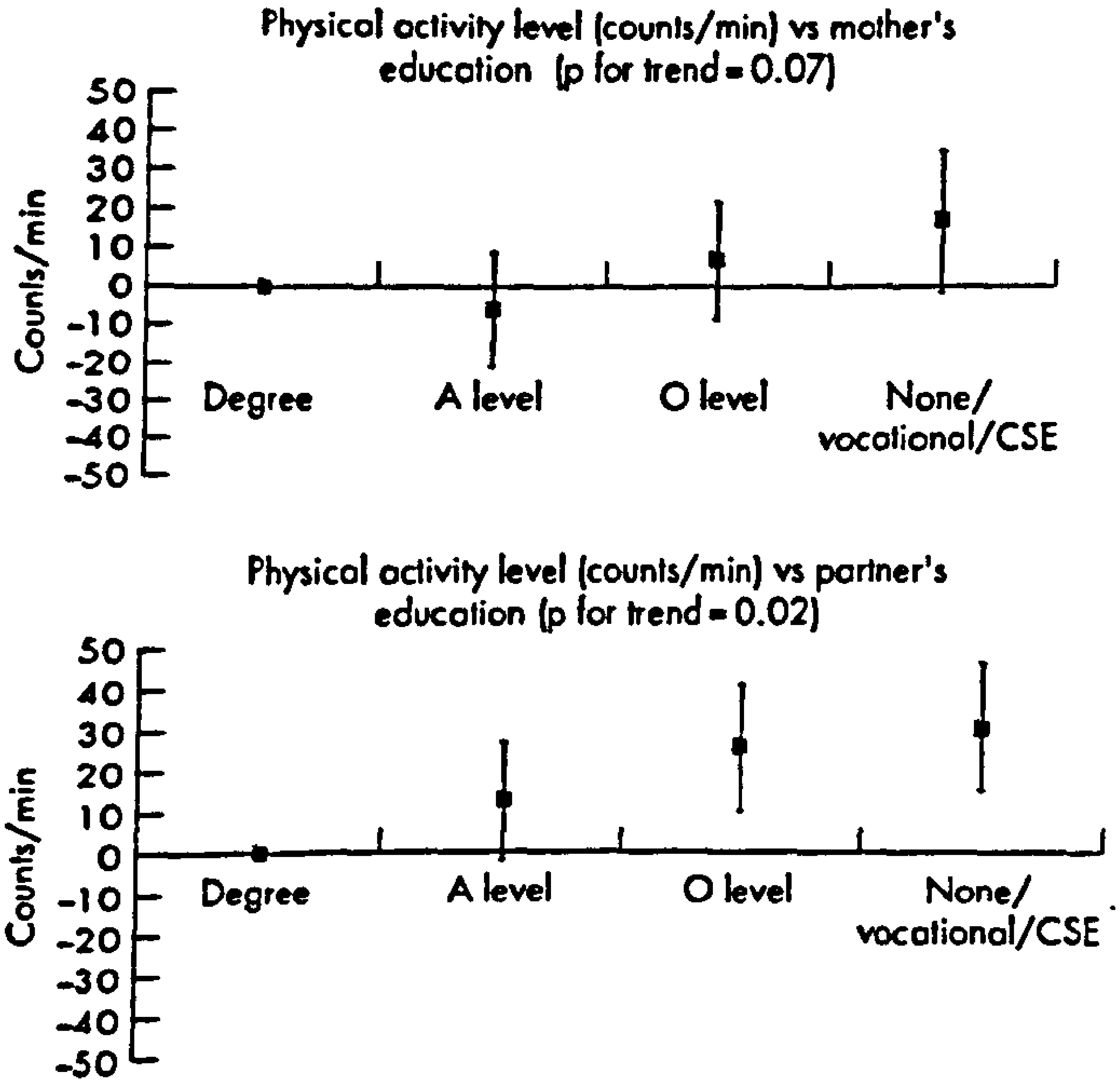

Figure 1 Regression analysis of socioeconomic variables on physical activity level (counts/min, 95% CI). The categories none/CSE and vocational have been combined. Reference group—degree. MVPA, moderate to vigorous physical activity.

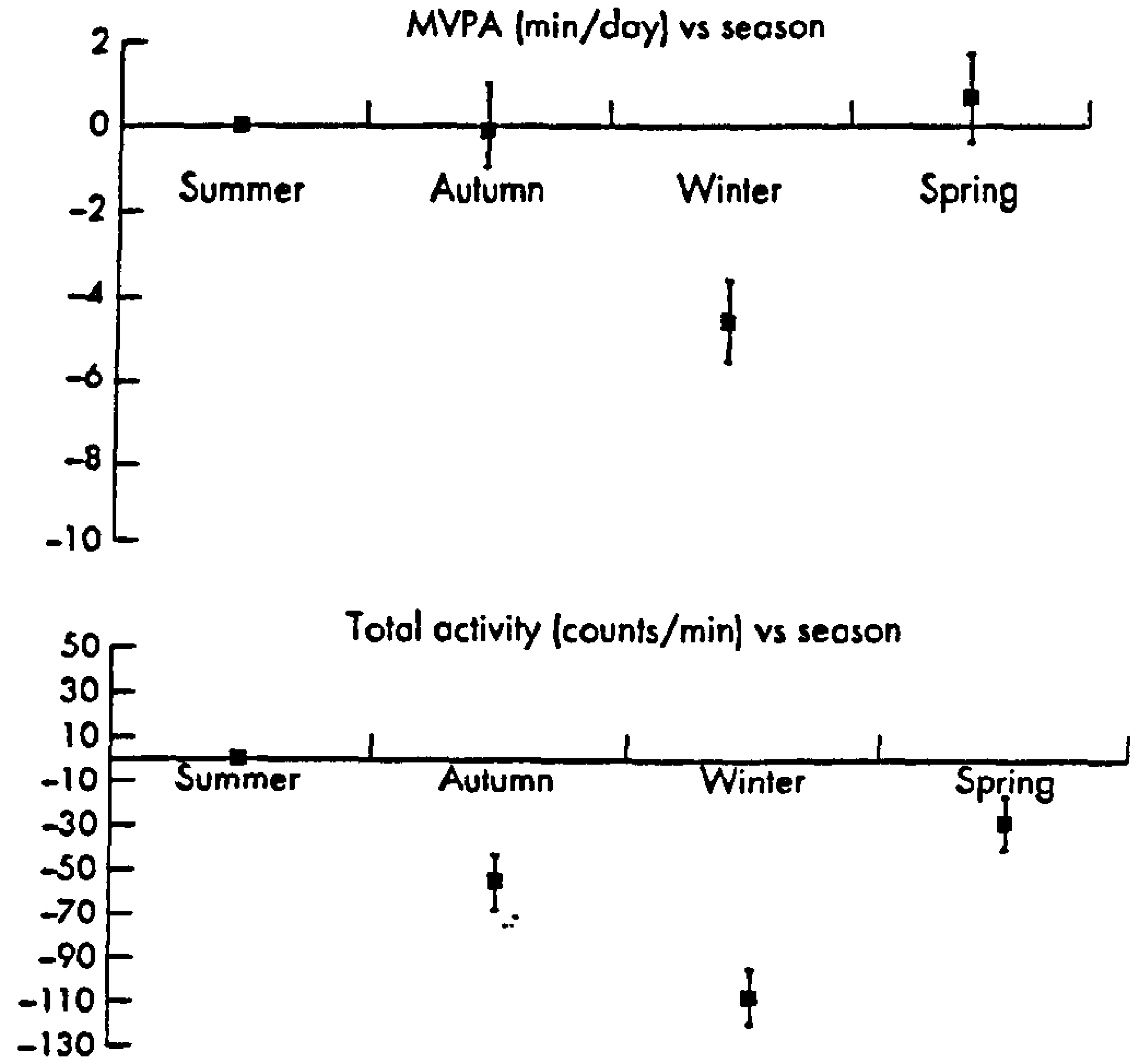

Figure 2 Regression analysis of effect of season on physical activity level and moderate to vigorous physical activity (MVPA). Seasons: summer (baseline), 1 June – 31 August; autumn, 1 September – 30 November; winter, 1 December – 28 February; spring, 1 March – 31 May. p for ANOVA <0.001. MVPA is mean minutes of MVPA over the measurement period—that is, total minutes of MVPA/number of valid days measurement.

generate standard deviation scores, and cut-offs of BMI >1.04 (85th centile) and BMI >1.64 (95th centile) were applied.[25] We used both criteria because there is no universal agreement about which is more appropriate, and to allow greater comparison with other studies that have used both.

RESULTS

A total of 7159 children attended the 11-year clinic and 6622 (92.5%) agreed to wear an Actigraph. Of the children who agreed to participate, 2662 boys and 2933 girls returned Actigraphs that satisfied the validity criteria. Children who provided valid recordings differed from children who did not provide valid recordings in terms of age, weight, BMI, sex and pubertal status but the size of the differences were small. More girls than boys returned instruments with valid data (81% girls vs 76% boys; p<0.001). Parental variables were not strongly associated with compliance. Children were more likely to comply if their mother had a higher level of education but again the differences were small. Full details of these differences and their implications have been reported elsewhere.[22]

The one way ANOVA indicated a difference between the activity levels of children with different numbers of valid days' measurement ($F = 8.14_{4,5591}$, p<0.001). Activity levels on day 1 of measurement were on average 17 (95% CI 10 to 24) counts/min higher than the average of subsequent days, indicating that the instrument may have a very small, "reactive" effect. Linear regression, allowing for multiple measurements per child, also indicated that day 1 of measurement tended to show slightly higher activity levels than subsequent days (p for trend <0.001). We have reported this fully in a previous methods paper.[22] We do not believe this magnitude of effect is meaningful.

Table 1 shows the main descriptive and physical activity data for boys and girls. Overall, boys had higher activity levels than girls during both weekdays and weekend days. Boys also participated in more MVPA. The largest sex differences were seen in the proportion of children meeting recommended activity levels. Both boys and girls spent most of their active

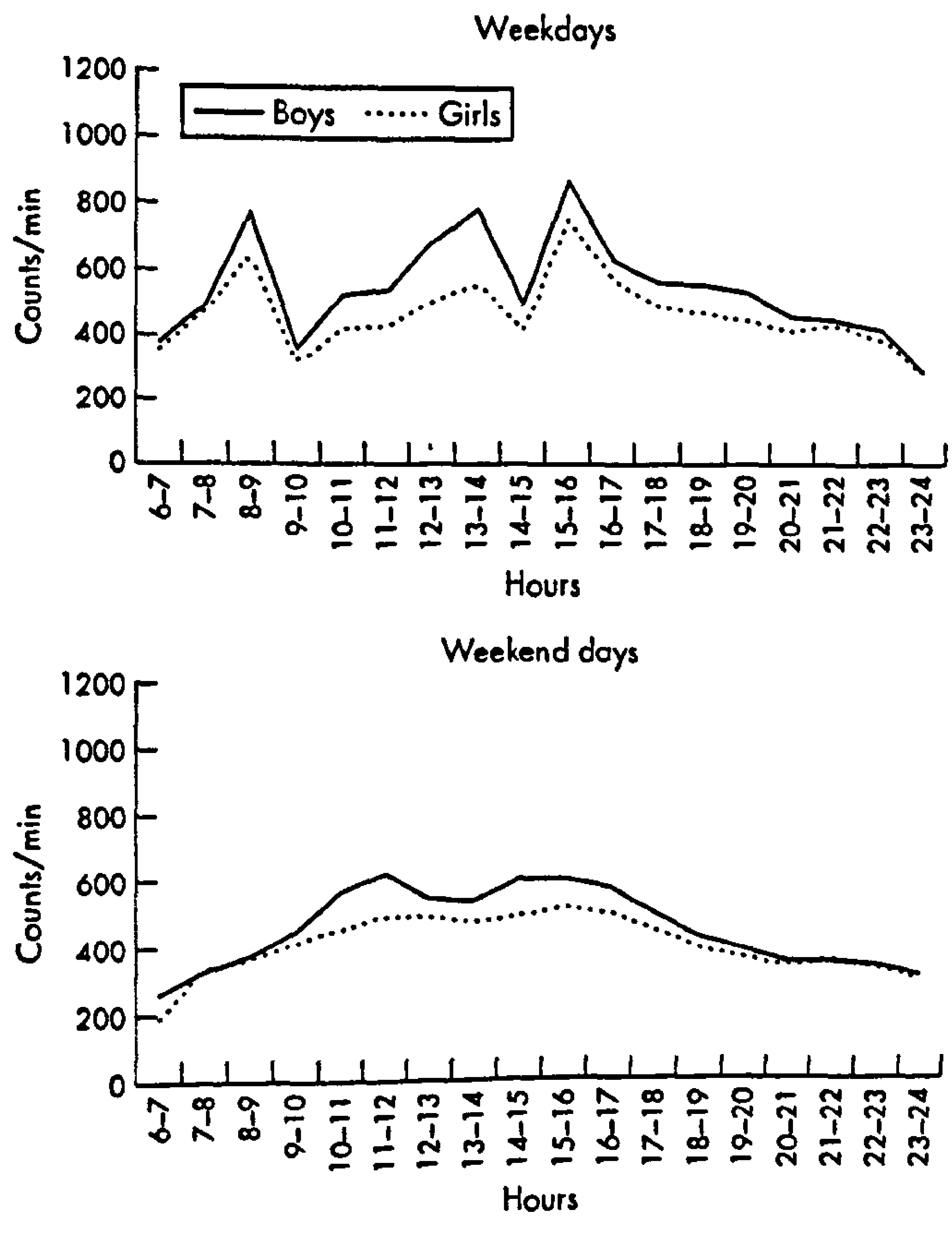

Figure 3 Daily (06:00–24:00 h) physical activity patterns of boys and girls, weekdays and weekend days. Plotted values are medians—physical activity level (counts/min).

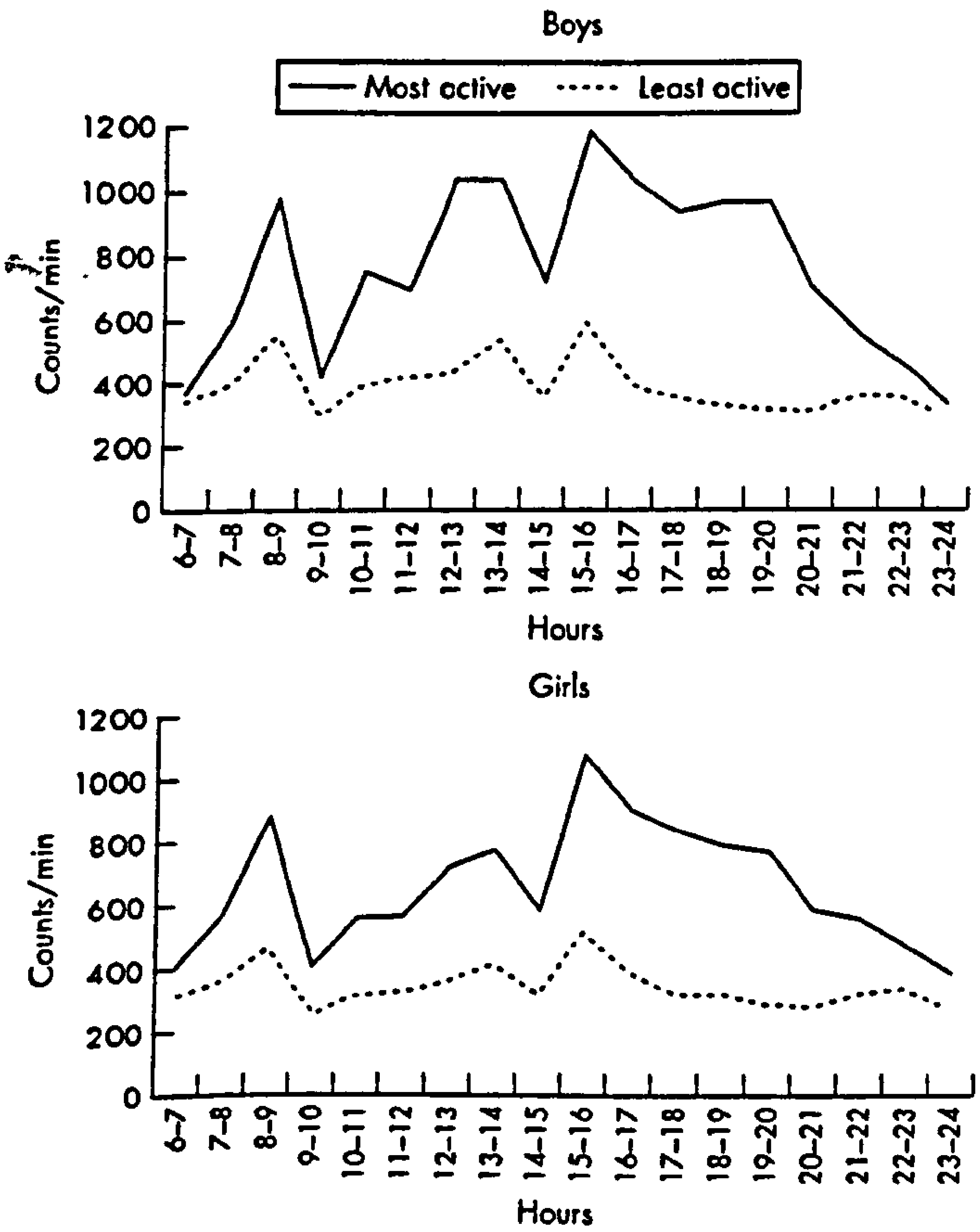

Figure 4 Daily (06:00–24:00 h) physical activity patterns of the most active and least active (extreme quintiles) boys and girls, weekdays. Plotted values are medians—physical activity level (counts/min).

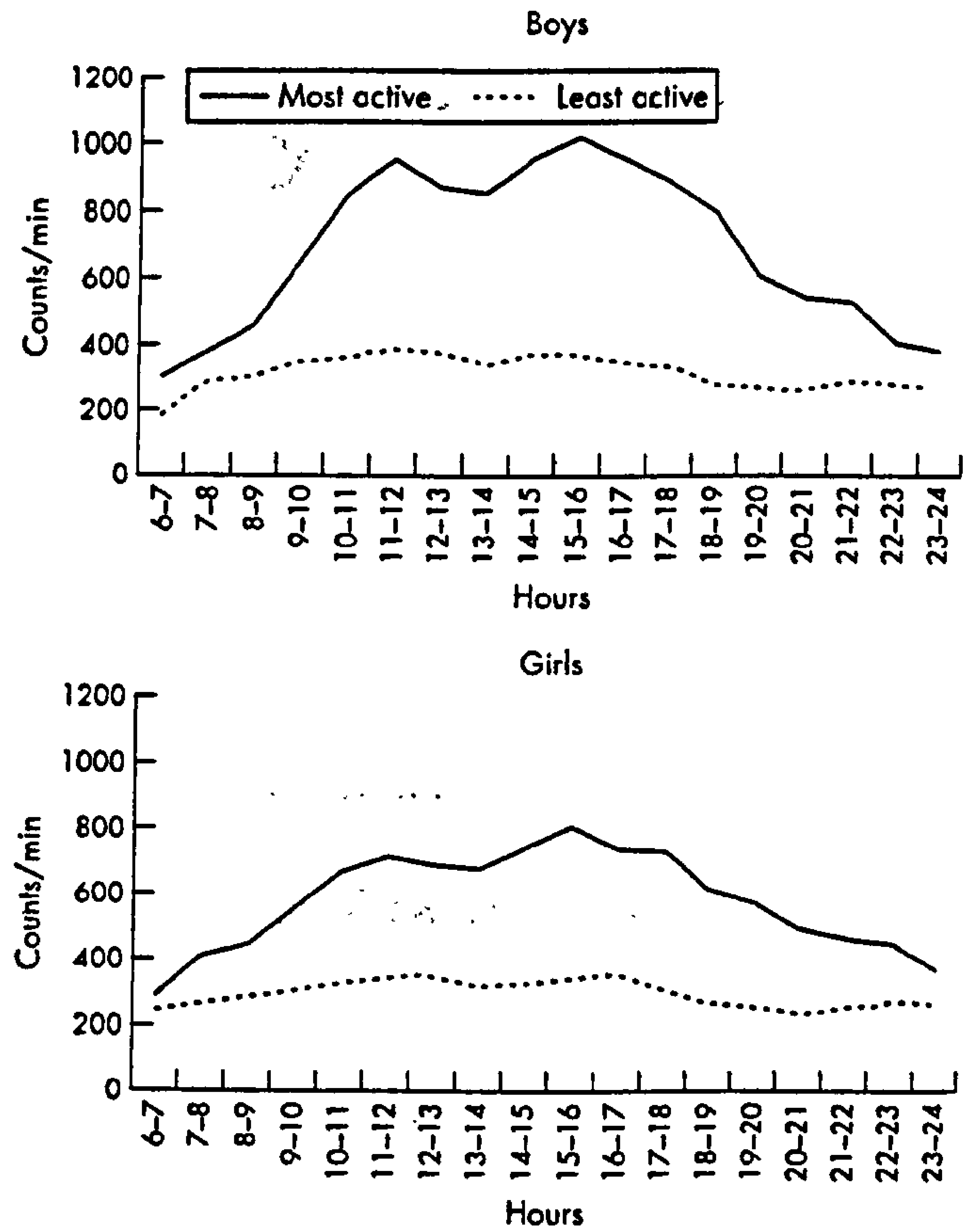

Figure 5 Daily (06:00–24:00 h) physical activity patterns of most and least active (extreme quintiles) boys and girls, weekend days. Plotted values are medians—physical activity level (counts/min).

time in light intensity activity (200–3599 counts/min). Forty per cent of boys and 22% of girls averaged at least one bout per day of MVPA lasting at least 5 min; 5% of boys and 2% of girls averaged at least one 10-min bout and <1% of both boys and girls averaged at least one 20-min bout.

Social class was inversely associated with total physical activity (p for trend <0.001), but the association was lost after adjustment for age, sex, maternal age, season and mother and partner's education. Social class was not associated with MVPA in either unadjusted or adjusted models. Both the mother and partner's education level were inversely associated with activity level (p for trend <0.001 (both mother and partner). The association was lost for mother's education (p for trend = 0.07) and attenuated for partner's education (p for trend = 0.02), after adjustment for age, sex, season, maternal age and social class.

Figure 1 shows the association between mother and partner's education level and their child's activity level. There was no association between either the mother or partner's education level and minutes of MVPA. Figure 2 shows the influence of season on physical activity level (counts/min) and MVPA, adjusted for age and sex. Activity levels were lowest in winter. Figure 3 shows the daily physical activity patterns of boys and girls for weekdays and weekend days. Marked differences in activity patterns can be observed between weekdays and weekend days in both boys and girls. Weekdays demonstrate more peaks and troughs, probably representing the school day, with children sitting in classrooms interspersed with periods of free time and recreation. The activity patterns of boys and girls are very similar.

Figures 4 and 5 show the daily physical activity patterns of most and least active (highest/lowest quintiles) boys and girls for weekdays and weekend days. Again, the patterns of the two groups are remarkably similar, differing only in the amount of activity performed. During weekdays, the period between the end of school (mid-afternoon) and bedtime seems to be the period of the day when the largest differences in activity occur. During weekend days, patterns are again very similar with larger differences in activity levels being seen in the boys.

The prevalence of overweight and obesity varies considerably, according to the method of derivation. Using the IOTF criteria, 17% of children were categorised as overweight and 5% obese. Using the 1990 centiles, 13% were overweight and 15% obese. Table 2 shows how physical activity varied by children's level of overweight or obesity. In both analyses, activity levels were lower in both the overweight and obese boys and girls. In boys, a graded inverse relationship was apparent across normal, overweight and obese categories, whereas in girls the differences were seen between normal and the other two categories—differences between overweight and obese girls were small.

Figure 6 shows the differences in activity levels by pubertal stage. For girls, Tanner stages 1–5 were used. For boys, analyses were restricted to Tanner stages 1–4 as probably any boy at this age would not be in Tanner stage 5. All analyses were restricted to those children who had returned their puberty questionnaire within 16 weeks of obesity measurement. This study confirms that self-reported pubertal stage is inversely associated with physical activity girls and to a lesser extent in boys.

DISCUSSION

Our study has two important findings. First, compared with adults, children participate in high volumes of physical activity, but few children—specially girls—meet the current health

Table 2 Physical activity (counts/min) by overweight/obesity status

	Normal	Overweight	Obese	p for trend*
IOTF cut-offs				
Boys	657.9 (544.6–790.7)	592.1 (487.4–739.7)	540.2 (442.9–636.5)	<0.001
n	2108	412	114	
Girls	535.6 (448.5–643.7)	508.5 (433.1–602.9)	510.6 (440.2–599.7)	0.001
n	2227	529	139	
All	590.6 (484.4–721.1)	542.7 (454.4–673.1)	520.0 (442.6–625.4)	<0.001
n	4335	941	253	
British 1990 centiles				
Boys	661.3 (548.1–796.6)	615.5 (502.0–730.4)	582.1 (475.3–723.1)	<0.001
n	1869	337	428	
Girls	538.3 (451.1–644.8)	513.0 (426.9–611.3)	506.6 (435.0–597.5)	<0.001
n	2098	378	419	
All	591.9 (486.1–723.0)	554.1 (449.4–682.1)	537.6 (455.4–659.3)	<0.001
n	3967	715	847	

Values are median (IQR) for counts/min.
*From regression of log counts/min on obesity (entered as a linear term).

related recommendation of 60 min of MVPA daily. Second, very little activity is performed in sustained bouts at a level that would provide promote cardiorespiratory fitness.

Total physical activity

In keeping with previous studies,[4,5] boys were more active than girls (median = 644 counts/min vs 529 counts/min). Cooper *et al*[26] reported typical activity levels of between 200 and 400 counts/min in normal, overweight and obese adults from the same geographical region as our children. This indicates that children's activity level is around double that of adults. However, as levels of childhood overweight and obesity are rising,[8,10–12] it seems likely that these levels of activity, although higher than adults, are in fact low.

Light, moderate and vigorous intensity activity

Recommendations for healthy levels of physical activity in children focus exclusively on MVPA (at least 60 min of MVPA daily). The median time spent in MVPA in this study is 20 min/day (boys: 25 min/day; girls: 16 min/day). These figures are considerably lower than those reported for European and American children. Riddoch *et al*[5] reported 192 min/day and 160 min/day in 9 year-old European boys and girls, respectively. Trost *et al*[4] reported that American children achieved 100 min/day of MVPA in the children most closely approximating the age of our children (grades 4–6). Similarly, Pate *et al*[6] reported median values of 146 min/day (boys) and 111 min/day (girls) in 10-year-old American children. These differences are likely to be caused by the use of different cutpoints of accelerometer counts to define the lower threshold of moderate intensity activity. Sleap and Tolfrey[27] have highlighted the wide disparity of conclusions that can be reached when different thresholds of light, moderate and vigorous activity are applied.

It should be a matter of some concern that only 5.1% of boys and 0.4% of girls achieved the current recommended level of activity. For adults, 45–60 min of MVPA is recommended to prevent obesity[1] and one would hope that most children—known to be more active than adults—would achieve at least this level at this age. It is a sobering thought that children's activity levels actually peak at around this age and decline precipitously during adolescence.[4,28–30]

Daily/weekly patterns of activity

Children are more active during weekdays than weekend days, although differences are small (31 counts/min). However, the reasons for this are not clear. Both boys and girls follow similar daily activity patterns. The period 11:00–14:00 h seems to be a time when boys are substantially more active than girls on both weekdays and weekend days. During weekdays, the morning travel to school period, lunch break and the immediate after-school

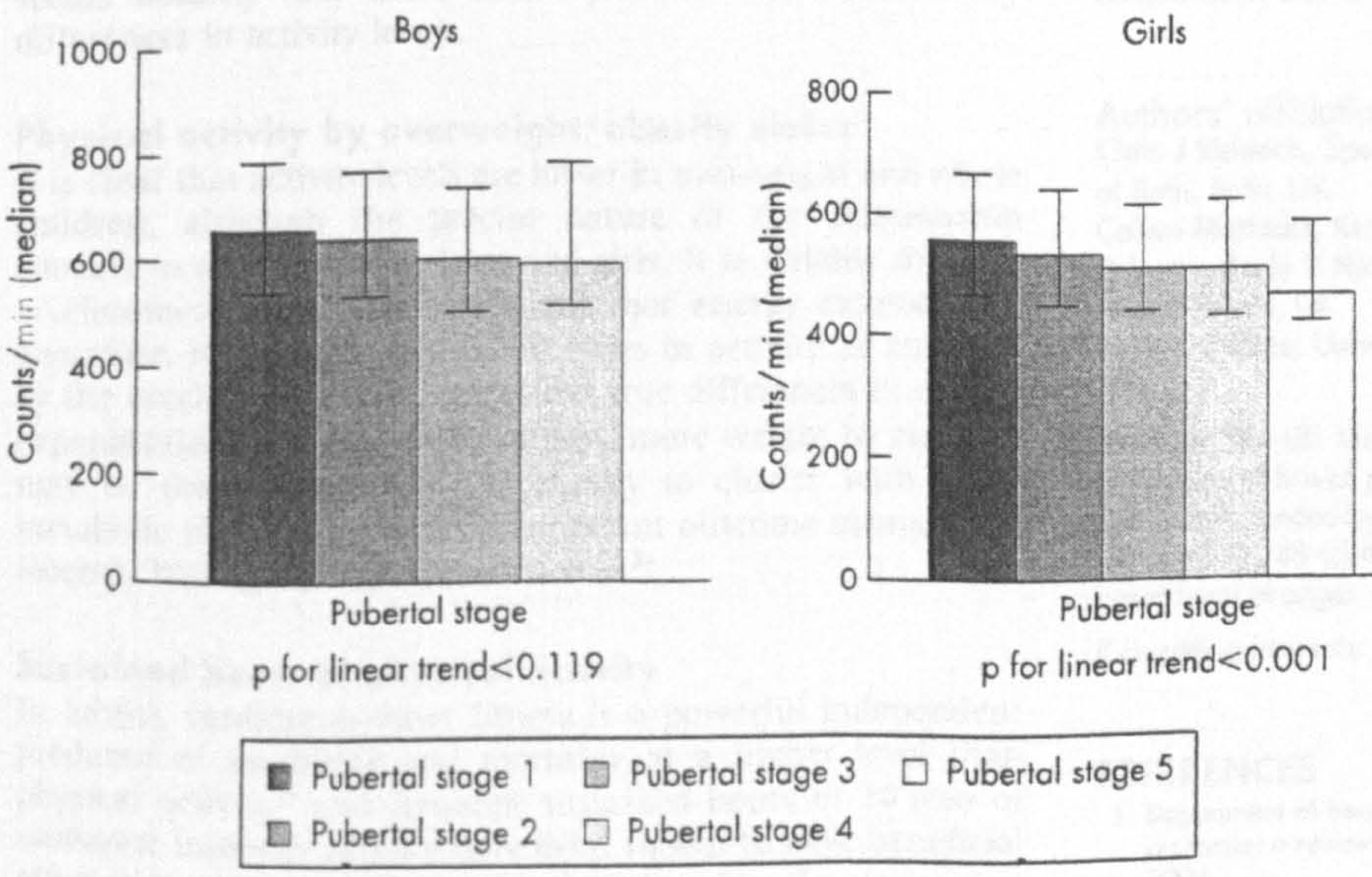

Figure 6 Physical activity levels by pubertal stage in boys and girls.

What is already known on this topic

- From a range of previous studies mostly using self-report methodology, children's activity levels are thought to be inadequate for health.
- Boys are considered more active than girls at all ages.

What this study adds

- This study is one of the first to use objective measurement techniques in a large, representative cohort of children, reporting activity data that are more valid and generalisable than previous studies.
- These data show levels and patterns of physical activity which, in many children, may be inadequate to promote good health.

period are the key times when children are most active. At the weekend, activity patterns are smoother, without the marked peaks and troughs seen on weekdays.

The most and least active children have almost identical daily activity patterns, albeit at different levels. Of particular note is the apparent importance during weekdays of the period from the end of school to bedtime (15:00 h onwards). It is during this period that the active children seem to be substantially more active, with differences between the two groups exceeding 700 counts/min and remaining substantial throughout the evening period. At the weekends, inactive children exhibit extremely flat activity profiles of between 200 and 400 counts/min throughout the day. Conversely, the most active children show peaks of activity during late morning and mid afternoon.

Modifying effects of season and socioeconomic factors

Seasonal influences are relatively strong with a summer–winter difference of 108 counts/min. Fisher *et al* reported similar seasonal differences in young children, a range of 125 counts/min.[31] The most active season for both studies was summer.

Neither social class nor the mother's education level was associated with either physical activity level or MVPA. Only the partner's education level demonstrated an association with activity level. Kimm *et al*[32] reported that lower levels of parental education were associated with greater rates of decline in activity through adolescence in children in the USA. In a study of Scottish children, socioeconomic position was not associated with objectively measured activity levels after adjustment for age, sex, BMI, and month of measurement.[33] Similarly, a systematic review found no evidence of an association between children's physical activity and socioeconomic position.[34] Socioeconomic conditions in childhood are related to mortality later in life[35] and also the increasing prevalence of childhood obesity is strongest in children from lower socioeconomic strata.[9] Conversely, Dummer *et al*[36] have reported no association between obesity and indices of deprivation. From our data, it seems unlikely that these health patterns are explained by differences in activity levels.

Physical activity by overweight/obesity status

It is clear that activity levels are lower in overweight and obese children, although the precise nature of the relationship appears to differ between boys and girls. It is notable that the accelerometer measures movement, not energy expenditure. Therefore, it is possible that differences in activity as recorded by the accelerometer may not reflect true differences in energy expenditure, as heavier children have more weight to move. It may be that the tendency of obesity to cluster with other metabolic measures is a more important outcome measure, as recently highlighted by Andersen *et al.*[37]

Sustained bouts of physical activity

In adults, cardiorespiratory fitness is a powerful independent predictor of morbidity and mortality at a higher level than physical activity[38] and frequent sustained bouts of 10 min of moderate intensity activity have been shown to have beneficial effects not only on cardiorespiratory fitness, but also on a range of cardiovascular risk factors.[39] In this study, few children achieved sustained bouts of MVPA. Our data support those of Trost *et al*[8] who reported that sustained 10-min and 20-min bouts of MVPA were extremely rare in children in the USA. Our results also concur with earlier studies of children using heart rate monitoring,[40] which also showed very low frequency of sustained bouts of activity. It is unsurprising that children do not achieve many sustained bouts of activity, as the natural tempo of their activity is characterised by frequent short bursts of activity lasting just seconds.[41] The health implications of such a sporadic activity pattern are unknown.

Physical activity levels by pubertal stage

We have shown that physical activity level decreases with increasing pubertal stage, most notably in girls. We cannot imply cause and effect, and we cannot separate out the biological influence of physical development and the psychosocial changes that occur during this period. Possibly both are important contributors to activity status and this will be a focus for future papers using longitudinal data through ages 11–15.

CONCLUSIONS

Although many children achieve relatively high volumes of activity compared with adults, few children achieve the level of MVPA recommended for health, particularly girls. These children may be predisposed to the development of childhood obesity, the early onset of cardiovascular risk factors and ultimately chronic disease.

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Authors' affiliations

Chris J Riddoch, Sport and Exercise Science, School for Health, University of Bath, Bath, UK
Calum Mattocks, Kevin Deere, Jo Saunders, Jo Kirkby, Kate Tilling, Sam D Leary, Andy R Ness, Department of Social Medicine, University of Bristol, Bristol, UK
Steven N Blair, University of South Carolina, Columbia, South Carolina, USA

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Competing interests: None.

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Appendix 5

BMJ

Early life determinants of physical activity in 11 to 12 year olds: cohort study

Calum Mattocks, Andy Ness, Kevin Deere, Kate Tilling, Sam Leary, Steven N Blair and Chris Riddoch

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BMJ

RESEARCH

Early life determinants of physical activity in 11 to 12 year olds: cohort study

Calum Mattocks, research associate,[1] Andy Ness, professor of epidemiology,[2] Kevin Deere, research assistant,[1] Kate Tilling, senior lecturer in medical statistics,[3] Sam Leary, statistician,[1] Steven N Blair, professor,[4] Chris Riddoch, professor[5]

[1]Department of Social Medicine, University of Bristol, Bristol

[2]...t of Oral and Dental ...istol Dental School

[3]Department of Social Medicine, University of Bristol, Bristol BS8 2PR

[4]Department of Exercise Science, Arnold School of Public Health, University of South Carolina, USA

[5]...nd Exercise Science, School for Health, ... Bath

...dence to: C Mattocks cmattocks@bristol.ac.uk

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ABSTRACT

Objective To examine factors in early life (up to age 5 years) that are associated with objectively measured physical activity in 11-12 year olds.

Design Prospective cohort study.

Setting Avon longitudinal study of parents and children, United Kingdom.

Participants Children aged 11-12 years from the Avon longitudinal study of parents and children.

Main outcome measure Physical activity levels in counts per minute (cpm) and minutes of moderate to vigorous physical activity for seven days measured with a uniaxial actigraph accelerometer.

Results Valid actigraph data, defined as at least three days of physical activity for at least 10 hours a day, were collected from 5451 children. Several factors were associated with physical activity at ages 11-12 years. Regression coefficients are compared with the baseline of "none" for categorical variables: maternal brisk walking during pregnancy (regression coefficient 5.0, 95% confidence interval −8.5 to 18.5; cpm for <1 h/wk and ≥2 h/wk of physical activity 17.7, 5.3 to 30.1), maternal swimming during pregnancy (21.5, 10.9 to 32.1 and cpm for <1 h/wk and ≥2 h/wk of physical activity 24.2, 7.8 to 40.7), parents' physical activity when the child was aged 21 months (28.5, 15.2 to 41.8 and cpm of physical activity for either parent active and both parents active 33.5, 17.8 to 49.3), and parity assessed during pregnancy (2.9, −7.6 to 13.4 and cpm of physical activity for 1 and ≥2 parity 21.2, 7.1 to 35.3).

Conclusions Few factors in early life predicted later physical activity in 11-12 year olds. Parents' physical activity during pregnancy and early in the child's life showed a modest association with physical activity of the child at age 11-12 years, suggesting that active parents tend to raise active children. Helping parents to increase their physical activity therefore may promote children's activity.

INTRODUCTION

Regular physical activity is beneficial to the health of adults and is thought to be beneficial to the health of children.[1,2] Although there is less evidence of the benefit to children,[3] activity in childhood may be an important determinant of health in adulthood for several reasons. A systematic review of physical activity in adolescents and health suggests direct and indirect pathways by which physical activity in youth might affect later health.[4] Some risk factors for diseases as adults are associated with lower levels of physical activity in childhood.[5-7] Thus a hypothetical pathway for disease could be from fetal and early life factors to physical activity in childhood to childhood risk factors for disease in adulthood to disease in adulthood.[8] In support of this hypothetical pathway, associations have been reported between early life factors and childhood obesity. For example, birth weight and parental obesity both predict a child's obesity at age seven.[9] Some evidence also shows that premature babies have poorer motor coordination in childhood[10] and that such children may be less active than their peers.[11]

Physical activity is a complex multifactorial behaviour that is influenced by environmental and biological factors.[12] Although there is an extensive literature on the psychosocial and environmental factors that influence physical activity in children, much of it is cross sectional[13] and little is known about early life influences on children's physical activity.[8] One prospective study found that risk factors in early life for a sedentary lifestyle (<300 minutes of self reported physical activity per week) at age 10-12 years were being female, being the oldest sibling, having a high family income at birth, high maternal education at birth, and lower maternal reported physical activity of children at age 4 years.[8] To our knowledge no study has examined the influences in early life on children's objectively measured physical activity in a contemporary cohort with extensive data on early life. Objective methods of measuring physical activity have advantages over subjective methods, particularly in children, and should enable the nature of the associations between physical activity and health to be characterised more precisely.[14]

We examined the factors in early life (up to age 5 years) that are associated with objectively measured physical activity in a large contemporary cohort of children aged 11-12 years.

METHODS

The Avon longitudinal study of parents and children (ALSPAC) is a geographically based birth cohort that has been described in detail previously.[15] Briefly, all pregnant women in the former Avon health area who had an expected delivery date between 1 April 1991 and 31 December 1992 were invited to take part in the study. Overall, 14 541 women were enrolled, totalling 14 062 live births.

From pregnancy and continuing to this day, questionnaires have been sent to the mothers, their partners (the partner at the time the questionnaire was administered may not have been the biological father), and the children inquiring about their health and lifestyle, the parents' circumstances, and the health and development of the child. Since age 7 the children have been invited to research clinics for a series of physiological and psychometric measures. The children gave written assent from age 10 (cosigned by the main carer). For the study on physical activity verbal consent was given by the child and main carer.

Physical activity data

Children who attended the study clinic at age 11 were asked to wear an actigraph accelerometer (Actigraph AM7164 2.2; LLC, Fort Walton Beach, Fl) for seven days. The methods are described elsewhere.[16] Briefly, the actigraphs were initialised to start recording at 5 am on the day after the clinic visit. The children were given a timesheet to record the times that the actigraph was put on and taken off each day. They were also asked to record any times (in minutes) that they swam or cycled each day as the actigraph does not record cycling well and cannot be worn for swimming. The actigraphs were downloaded on to a computer and a customised macro was used to derive a series of variables describing levels and patterns of physical activity. Two outcome variables were used in this analysis: average counts per minute (cpm) over the valid measurement period—a measure of total activity that has been validated against activity energy expenditure estimated by doubly labelled water ($r=0.54$; $P<0.01$)[17]; and moderate to vigorous physical activity, as current recommendations for physical activity in children are framed in terms of time spent each day in such activity.[1] We used a cut-off point of cpm greater than 3600 to define moderate to vigorous physical activity.[18]

Table 1 | Potential risk factors up to age 5 years for obesity in adulthood

Potential determinant	Time of recording or method used to derive data	Categories or units
Birth outcomes:		
[illegible]	Birth	Continuous (100 g)
[illegible] index	Birth (birth weight/heel-crown length^3)	Continuous (kg/m^3)
Crown-heel length	Birth	Continuous (cm)
Head circumference	Birth	Continuous (cm)
Gestational age	Reported date of last menstrual period	Continuous (weeks)
Prenatal characteristics:		
Maternal body mass index before pregnancy	Questionnaire at 12 weeks	Continuous (kg/m^2)
Partner's body mass index before the pregnancy	Questionnaire at 12 weeks	Continuous (kg/m^2)
Maternal smoking during pregnancy	Questionnaire at 32 weeks	Yes or no
Partner smoking during the pregnancy	Questionnaire at 18 weeks	Yes or no
Maternal age at birth of child	Calculated from date of birth of mother	Years
Partner's age at birth of child	Calculated from date of birth of father	Years
Maternal brisk walking during pregnancy	Questionnaire at 18 weeks	Never, <1 h/wk, >2 h/wk
Maternal swimming during pregnancy	Questionnaire at 18 weeks	Never, <1 h/wk, >2 h/wk
Partner's physical activity	Questionnaire at 18 weeks	Hours per week
Parity*	Questionnaire at 18 weeks	0, 1, ≥2
Season of birth†	Birth records	
Early childhood (0-2 years):		
Activity	Questionnaire at 6 months	Combined score from 12 questions; possible range 12-72
Motor coordination	Questionnaire at 6 months	Combined score from 12 questions; possible range 12-72
Presence of partner	Questionnaire at 8 months	Yes or no
[illegible] activity	Questionnaire at 21 months	Days per week engaged in activity
[illegible]'s activity	Questionnaire at 21 months	Days per week engaged in activity
Time spent outside	Questionnaire at 24 months	<7, 7-13, or >13 (h/wk)
Breast feeding	Questionnaire at 6 months	Yes or no
Preschool (2-5 years):		
Time spent outside	Questionnaire at 38 months	<7, 7-13, or >13 (h/wk)
Time spent outside	Questionnaire at 54 months	<14, 14-20, or >20 (h/wk)
Television viewing	Questionnaire at 38 months	<10 or ≥10 h/wk
Television viewing	Questionnaire at 54 months	<10 or ≥10 h/wk
[illegible]on of night time sleep	Questionnaire at 30 months	Hours per night

*Number of previous pregnancies resulting in live birth or still birth.
†Winter=December to February; spring=March to May; summer=June to August; autumn=September to November.[22]

Table 2 | Children in Avon longitudinal study of parents and children who attended research clinic and had valid data on physical activity compared with those who did not at age 11-12 years. Values are numbers (percentages) unless stated otherwise

Characteristic	No of children	No valid data (n=1451)	No of children	Valid data (n=5451)	P value
Child variables:					
Mean (SD) age (years)	1451	11.86 (0.25)	5386	11.81 (0.23)	<0.001
Mean (SD) body mass index (kg/m²)	1417	19.5 (3.8)	5388	19.0 (3.3)	<0.001
Mean (SD) birth weight (g)	1414	3445 (537)	5121	3433 (523)	0.43
Boys	794	54.7	2593	47.6	<0.001
Girls	657	45.3	2858	5204	
Social class*:	1272		4806		
I and II	353	27.8	1428	29.7	0.19
III, non-manual	333	26.2	1308	27.2	
III, manual	375	29.5	1279	26.6	
IV and V	211	16.6	791	16.5	
Maternal education*:	1348		5029		
A level or university degree	196	13.5	825	16.4	0.04
O level	358	26.6	1343	26.7	
Vocational	464	34.4	1798	35.8	
None or CSE	330	24.5	1063	21.1	

*From I (high) to V (low).

We deleted from each file 10 or more minutes of consecutive zeros as we regarded these as periods when the monitor was not worn.[19] We also excluded any day of recording when the average cpm was less than 150 or more than 3 standard deviations above the mean[20] as we considered this level of physical activity to be behaviourally implausible. We considered activity data to be valid if the recording period was for at least 10 hours per day for at least three days.[16] The actigraphs were recalibrated when the batteries were changed—about every six months. Over the two year period of data collection, 267 actigraphs were used. Of the 518 calibrations, no adjustment was required in 394 (77%) cases.

Potential risk factors

We defined early life as the period from pregnancy to age 5 years as this includes some suggested critical periods of development: the intrauterine period, infancy, and the age of adiposity rebound. Age 5 is also a landmark for children as they start school and therefore their lives change noticeably. Potential risk factors were identified as characteristics in early life that were associated with physical activity in childhood,[8] obesity,[9] or other markers of the metabolic syndrome[5,6]; cardiorespiratory fitness or neuromotor function[10]; or activity behaviours that are known to display some tracking from early to later childhood.[8,21] Table 1 lists the potential risk factors, how they were derived, and the units used.

Potential confounders

We recorded socioeconomic variables at 32 weeks' gestation. The mother was asked to record her highest education level, which was categorised into none or CSE (exams at age 16), vocational, O level (exams at age 16, higher than CSE), A level (exams at age 18), or university degree. Social class groups were derived from the parents' occupation (classes I to V with III split into non-manual and manual) using the 1991 Office of Population Censuses and Surveys.[23] When the social class of the mother and partner differed, the lower of the two was used in the analysis to give the most variability within the variable.

Statistical analysis

We used three models to explore the role of confounders, with cpm as the outcome. Model 1 was adjusted

Table 3 | Associations between birth outcomes and counts per minute of physical activity in children aged 11-12 years from Avon longitudinal study of parents and children

	Model 1			Model 2		
Variable	No of children	Regression coefficient* (95% CI)	P value	No of children	Regression coefficient* (95% CI)	P value
Birth weight (100 g)	5058	−2.1 (−6.7 to 2.6)	0.383	4671	−0.4 (−6.3 to 5.5)	0.893
Ponderal index (kg/m³)	4045	1.3 (−3.4 to 6.0)	0.600	3738	1.0 (−3.8 to 5.9)	0.670
Head circumference (cm)	4144	−5.2 (−10.8 to 0.3)	0.063	3834	−3.5 (−9.2 to 2.2)	0.233
Crown-heel length (cm)	4094	−3.6 (−9.4 to 2.1)	0.217	3786	−1.9 (−7.9 to 4.0)	0.521
Gestation (weeks)	5127	−1.3 (−6.1 to 3.5)	0.599	4739	−2.4 (−7.7 to 2.9)	0.376

Model 1 adjusted for age and sex. Model 2 adjusted for age, sex, and parental social class by occupation and mother's education.
*Standardised regression coefficient: change in counts per minute per standard deviation of variable: birth weight 5.2, ponderal index 3.1, head circumference 1.5, crown-heel length 2.4, and gestation 1.8.

for age and sex. Model 2 was adjusted for age, sex, maternal education, and social class. We have previously shown that physical activity is negatively associated with socioeconomic status and that boys are more active than girls in this population: median 644 cpm (interquartile range 528-772) for boys and 529 cpm (444-638) for girls; P<0.001.[24] We therefore included sex and socioeconomic status as potential confounders rather than as potential determinants. Model 3* was adjusted for the confounders in model 1 but restricted to those with all available data from model 2. Measures of size at birth were additionally adjusted for gestational age. Season of birth was additionally adjusted for season of measurement, as all children were seen at about age 11 years and 9 months, so season of birth is likely to be related to season of measurement. Models were run separately for each characteristic—that is, they were not mutually adjusted. Analysis for models 1 and 2 was repeated with minutes of moderate to vigorous physical activity as the outcome. We repeated analyses in children who did not report swimming or cycling during the period of measurement. Analyses were carried out on boys and girls combined. To test for an effect modification of sex we introduced interaction terms (sex×exposure variable) into model 1. When evidence of an interaction existed we did the analyses separately for boys and girls. Moderate skewness was found in the activity variables. We did not transform data for the analyses but we did use robust standard errors. Such errors allow derivation of confidence intervals and standard errors on the basis of the actual distribution of the outcome variable in the dataset, rather than on an assumed underlying probability distribution.[25] We present the results for continuous variables as standardised regression coefficients, adjusted for the standard deviation of cpm for each model. Thus the regression coefficient for continuous variables is the difference in cpm associated with a 1 standard deviation change in the exposure variable. We present the results for categorical variables as normal regression coefficients.

RESULTS

A total of 11 952 children from the Avon longitudinal study of parents and children were invited to participate in study clinics at age 11 years. Of these, 7159 (59.9%) attended the clinic and 6622 (92.5%) agreed to wear an actigraph accelerometer. Of the children who agreed to participate, 5595 (84.5%) returned actigraphs that satisfied the validity criteria.[16] Children from multiple births, totalling 144, were excluded from the analyses to rule

Table 4 | Associations between prenatal characteristics and counts per minute of physical activity in children aged 11-12 years from Avon longitudinal study of parents and children

	Model 1			Model 2		
Variable	No of children	Regression coefficient (95% CI)	P value	No of children	Regression coefficient (95% CI)	P value
Maternal body mass index (kg/m²)*	4657	−3.2 (−8.3 to 1.9)	0.214	4394	−5.2 (−10.4 to 0.1)	0.053
Maternal smoking status during pregnancy:						
Non-smoking	3827	28.0 (14.2 to 48.1)	<0.001	3757	19.0 (4.7 to 333.3)	0.009
Smoking	698			664		
Partner's smoking status during the pregnancy:						
Non-smoking	3360	20.1 (10.0 to 30.2)	<0.001	3200	14.2 (3.4 to 25.0)	0.010
Smoking	1610			1456		
Maternal age at birth (years)	5127	−11.5 (−16.1 to −6.8)	<0.001	4739	−7.9 (−13.1 to −2.7) *	0.003
Maternal brisk walking during pregnancy (never as baseline):	1113			1041		
<1 h/wk	1384	−2.0 (−15.1 to 11.2)	0.022†	1339	5.0 (−8.5 to 18.5)	0.009†
≥2 h/wk	2199	12.4 (0.3 to 24.4)		2103	17.7 (5.3 to 30.1)	
Maternal swimming during pregnancy (never as baseline):	2538			2399		
<1 h/wk	1643	13.2 (2.8 to 23.6)	0.008†	1589	21.5 (10.9 to 32.2)	<0.001†
≥2 h/wk	498	20.0 (3.6 to 36.4)		485	24.2 (7.8 to 40.7)	
Parity (0 as baseline):	2331			2183		
1	1739	4.1 (−6.1 to 14.4)	<0.001†	1637	2.9 (−7.6 to 13.4)	0.012†
≥2	905	26.1 (12.6 to 39.6)		828	21.2 (7.1 to 35.3)	
Season of birth‡ (spring as baseline):	1174			1089		
Summer	1522	15.7 (3.2 to 28.1)	0.013	1420	16.7 (4.0 to 29.5)	0.010
Autumn	1469	31.9 (19.1 to 44.7)	<0.001	1337	34.1 (20.8 to 47.5)	<0.001
Winter	962	33.4 (20.0 to 46.8)	<0.001	893	34.7 (21.0 to 48.5)	<0.001

Model 1 adjusted for age and sex. Model 2 adjusted for age, sex, parental social class by occupation, and mother's education.
*Standardised regression coefficient: change in counts per minute per standard deviation (3.7) of variable.
†P for linear trend.
‡Winter=December to February; spring=March to May; Summer=June to August; Autumn=September to November. Additionally adjusted for season of measurement.

out non-independence in the data. The sample consisted of 5451 children (2593 boys and 2858 girls), mean age 11.8 years. Some small differences were found between the characteristics of children who provided valid data on physical activity and those who did not (table 2).

Tables 3-7 show the associations between variables and cpm for each model for each of the critical developmental periods. Results were similar after excluding children who reported swimming or cycling during the measurement period (data not shown). Results from model 3 were similar to those of model 1 (data not shown). Results for models 1 and 2 with moderate to vigorous physical activity as the outcome showed a similar pattern to cpm as the outcome. Therefore, only the results for counts per minute (cpm) are shown.

None of the birth outcomes was associated with physical activity at ages 11-12 years and this remained unchanged after adjustment for confounders (table 3).

Few of the prenatal characteristics were associated with physical activity (table 4). Mother's body mass index before pregnancy, parents' smoking status during pregnancy, mother's age at birth of the child, mother's physical activity, parity, and season of birth showed modest associations with physical activity. The associations for parents' smoking and maternal age attenuated after adjustment for socioeconomic status, whereas the associations for maternal physical activity during pregnancy strengthened slightly. Partner's body mass index, obesity in the mother and her partner, partner's age at birth, partner's physical activity, and presence of the mother's partner at home were not associated with later physical activity (data not shown).

Table 5 shows the associations between characteristics in childhood from age 0-2 years and physical activity. These associations tended to be modest and remained after adjustment. Parental activity was associated with later physical activity in the child.

Of the characteristics in preschool aged children, only television viewing at 38 and 54 months' follow-up showed any clear associations, although these were small. Little evidence was found that the other proxy measures of physical activity, time spent outside at 38 and 54 months, were associated with later physical activity.

Evidence was found of an interaction in only two of the variables so the results are presented for the analyses of boys and girls combined. Sex×brisk walking and sex×motor coordination showed evidence of effect modification (P=0.020 and P=0.008). Table 7 shows the analyses for boys and girls separately when the exposure variable was modified by sex.

DISCUSSION

Few of the early life factors studied were associated with later physical activity in 11-12 year olds and for those that were the associations were modest.

Birth outcomes and prenatal exposures

None of the birth outcomes was associated with physical activity. A recent study found that children of low birth weight (<2500 g) reported slightly fewer minutes of activity per week at age 10-12 than their peers of higher birth weight. The same study, however, reported no difference in sedentary lifestyle by birth weight.[8]

Table 5 | Associations between early exposures in childhood (0-2 years) and counts per minute of physical activity in children aged 11-12 years from Avon longitudinal study of parents and children

	Model 1			Model 2		
Variable	No of children	Regression coefficient (95% CI)	P value	No of children	Regression coefficient (95% CI)	P value
Activity at 6 months*	4574	−2.13 (−6.99 to 2.72)	0.389	4303	−1.49 (−6.49 to 3.50)	0.558
Motor coordination at 6 months*	4736	5.33 (0.12 to 10.54)	0.045	4452	5.77 (0.25 to 11.29)	0.041
With partner at 8 months:						
Yes	4675	23.6 (−3.4 to 50.5)	0.086	4422	9.5 (−21.5 to 40.5)	0.547
No	138			103		
Parents activity at 21 months (neither active as baseline):	917			866		
Either active	1968	29.4 (16.2 to 42.5)	<0.001†	1876	28.5 (15.2 to 41.8)	<0.001†
Both active	881	31.5 (16.1 to 46.8)		844	33.5 (17.8 to 49.3)	
Time outside at 24 months (<7 h/wk as baseline):	1026			946		
7-13 h/wk	1284	−15.5 (−29.1 to −1.8)	0.085†	1224	−12.9 (−27.1 to 1.2)	0.196†
>13 h/wk	2349	−8.5 (−21.0 to 3.9)		2211	−6.6 (−19.5 to 6.4)	
Breast fed at 6 months (still breast feeding as baseline):	1703			1629		
Yes	2309	7.2 (−3.3 to 17.7)	0.238†	2157	−1.3 (−12.4 to 9.8)	0.749†
Never	817	10.9 (−3.2 to 25.0)		749	−5.9 (−21.5 to 9.6)	

Model 1 adjusted for age and sex. Model 2 adjusted for age, sex, parental social class by occupation, and mother's education.
*Standardised regression coefficient: change in counts per minute per standard deviation of variable: activity at 6 months 6.3 and motor coordination at 6 months 5.2.
†P for linear trend.

Table 6 | Associations between exposures in preschool children (2-5 years) and counts per minute of physical activity in children aged 11-12 years from Avon longitudinal study of parents and children

	Model 1			Model 2		
Variable	No of children	Regression coefficient (95% CI)	P value	No of children	Regression coefficient (95% CI)	P value
Time outside at 38 months (<7 h/wk as baseline):	1916			1810		
7-13 h/wk	1101	−4.1 (−16.8 to 8.5)	0.588*	1043	−4.4 (−17.4 to 8.6)	0.230*
>13 h/wk	1569	−5.6 (−16.8 to 5.5)		1464	−10.2 (−21.8 to 1.5)	
Time outside at 54 months (<14 h/wk as baseline):	952			894		
14-20 h/wk	1531	14.2 (0.7 to 27.6)	0.112*	1439	9.0 (−4.9 to 22.9)	0.436*
>20 h/wk	1956	10.6 (−2.4 to 23.5)		1849	4.6 (−8.8 to 17.9)	
Television viewing at 38 months:						
<10 h/wk	3566	−6.1 (−18.0 to 5.9)	0.318	3367	−12.4 (−24.9 to 0.1)	0.051
>10 h/wk	1037			967		
Television viewing at 54 months:						
<10 h/wk	1432	−4.7 (−15.0 to 5.7)	0.375	1354	−11.0 (−21.8 to −0.2)	0.046
>10 h/wk	3035			2853		
Sleep at 30 months (hours per night)†	4589	3.0 (−1.8 to 7.8)	0.218	4310	−0.55 (−5.8 to 4.7)	0.837

Model 1 adjusted for age and sex. Model 2 adjusted for age, sex, parental social class by occupation, and mother's education.
*P for linear trend.
†Standardised regression coefficient: change in counts per minute per standard deviation (0.96) of variable.

Body mass index of the mother before pregnancy but not her partner was weakly associated with physical activity. Previous studies have been inconsistent. One reported no relation between parental obesity and physical activity, assessed by heart rate monitor in 101 prepubescent girls.[26] A systematic review found that parental obesity was positively associated with physical activity in 4-12 year olds.[13]

Smoking in the mother and her partner were both positively associated with physical activity. This is surprising because maternal smoking during pregnancy is associated with childhood obesity.[9] The association we have shown was similar for smoking in both the mother and the partner and attenuated after adjustment, so may be a result of the social patterning of smoking behaviour. We have previously shown a negative association between physical activity and socioeconomic status.[24]

Previous studies have reported a positive association between parental activity and children's activity although there is some inconsistency. Eleven of 29 studies in a systematic review showed a positive association between parental physical activity and children's physical activity whereas findings in the remainder were equivocal.[13] In our study, maternal activity during pregnancy (specifically brisk walking and swimming) was positively associated with physical activity in the children. It is unlikely that this is due to biological factors in utero but is more likely that physical activity during pregnancy is a marker for later maternal physical activity and that this in turn influences children's physical activity.

Parity is also a measure of the number of older siblings and we found that physical activity was positively associated with parity. This confirms the findings of a previous study, which reported that birth order was positively associated with physical activity and negatively associated with a sedentary lifestyle in 10-12 year olds.[8]

The association with season of birth is difficult to explain. Children born during summer to winter were more active than those born in spring. Season of birth is associated with a range of mental and physical disorders.[27] It is possible that season of birth has an effect through the age at which children start school. In this study some children were measured while at primary school and some while at secondary school,

Table 7 | Associations between exposure and counts per minute of physical activity when evidence existed of effect modification by sex, adjusted for age

	Boys			Girls		
Variable	No of children	Regression coefficient (95% CI)	P value	No of children	Regression coefficient (95% CI)	P value
Maternal brisk walking during pregnancy (never as baseline):	517			596		
<1 h/wk	671	−0.1 (−21.5 to 21.2)	0.998*	713	−4.1 (−20.1 to 12.0)	<0.001*
≥2 h/wk	1074	−0.6 (−19.9 to 18.7)		1125	24.4 (9.4 to 39.4)	
Motor coordination†	2266	−1.55 (−9.57 to 6.45)	0.703	2470	11.63 (4.86 to 18.40)	0.001

*P for linear trend.
†Standardised regression coefficient: change in counts per minute per standard deviation (5.24) of variable.

WHAT IS ALREADY KNOWN ON THIS TOPIC

Identifying factors that influence physical activity in childhood may help develop better intervention strategies

Little is known about whether factors in early childhood might influence later physical activity

WHAT THIS STUDY ADDS

Factors in early life have limited influence on later physical activity in 11-12 year olds

Parental physical activity is associated with modest increases in children's activity

Encouraging activity among parents may help children to be active

where the environments may provide different opportunities for physical activity. It was not, however, possible to control for school type in this analysis. It is also known that a month of birth bias exists in many competitive sports, with those born earlier in the sports' season more likely to succeed at competitive sport[28] and it may be that early involvement in organised sport leads to increased physical activity in later life.[29]

Early childhood (0-2 years) and preschool (2-5 years)

None of the indicators of physical activity at age 0-2 years (activity at six months or time outside at 24 months) was associated with later physical activity. Tracking of physical activity tends to be weak to moderate[21 30] and it may be that the early measures of physical activity we chose lacked precision to detect an association with later physical activity. Parental physical activity at 21 months was associated with children's physical activity when two non-active parents were compared with either or both parents being active. Studies have reported that physical activity tends to aggregate in families.[31] A review, however, reported that the evidence for an association between parental and child's physical activity is limited.[32] A small association was found with motor coordination at six months. This is in agreement with a recent study that found a weak association between physical activity and motor skills.[11]

Few of the characteristics in preschool aged children (2-5 years) were associated with later physical activity. A small association was found, after adjustment, with television viewing at 38 and 54 months. One study recently reported no cross sectional association between television viewing and objectively measured physical activity.[33] A meta-analysis that included mainly cross sectional studies reported a weak relation between television viewing and physical activity (Pearson's coefficient $r=-0.096$, 95% confidence interval -0.080 to -0.112).[34] The modest associations we report here may result from the length of time between measures for television viewing and assessment of physical activity, as other factors may have had a greater influence before follow-up at 11 to 12 years.

Effect modification by sex

We found little evidence of effect modification by sex on most of the variables. Owing to the large number of tests for interaction it is possible that those showing evidence of effect modification did so by chance. We did find strong evidence of an association between maternal brisk walking during pregnancy and physical activity in girls but not in boys. A previous review reported that maternal physical activity is associated with physical activity in daughters more than in sons.[32]

Strengths and limitations of the study

The use of an objective measure of physical activity is a major strength of this study as it provides a more precise and accurate estimate than self report of the level of physical activity. The detailed measures available and the large sample size allowed us to test for associations of several potential determinants and allowed adequate exploration of the role of potential confounders.

Some of the variables were based on single questions therefore not validated questionnaires. This may have resulted in attenuated associations with children's physical activity owing to imprecision of measurement.[14] It is also possible that cohort attrition and biased participation in study resulted in an unrepresentative sample, which may limit generalisability. Children who participated in this study were more likely to be from socially advantaged backgrounds,[16] although the magnitude of social patterning in physical activity is small.[24] Several of the characteristics were based on questionnaires in which the questions changed slightly over time, making comparisons difficult.

Conclusions

We have shown that early life factors have limited influence on later physical activity in 11-12 year olds. This may have implications when developing guidelines for interventions to increase physical activity, as focusing on modifiable early life factors may have only a modest effect on later levels of physical activity. We have shown that children are slightly more active if their parents are active early in the child's life. This suggests that encouraging physical activity in parents may also influence their children to become more active, with the added advantage that physically active parents are healthier. Although we report few associations between early life factors and physical activity, future research should re-examine these associations in later adolescence when physical activity declines, particularly in girls.

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Contributors: CM organised the daily data collection tasks, was in charge of clinic organisation, preparation of activity monitors, and supporting documentation for each child; and carried out statistical analyses. He is guarantor. CR was the lead applicant for grant funding, was responsible for the overall design of measurement protocols, data collection, and analysis; organised the ethical procedures; and liaised with the funding body. KD participated in daily collection tasks, helped prepare the activity monitors and supporting documentation for each child, and provided input on drafts of this paper. KT was an applicant for grant funding, had overall responsibility for statistical analyses, and provided input on drafts of this paper. SL assisted with

statistical analyses and provided input on drafts of this paper. SNB was a collaborator on the grant; provided scientific input on all aspects of the study design, analysis, and reporting; and provided input on drafts of this paper. AN was an applicant for grant funding; provided input on all aspects of the study design and drafts of this paper; and was responsible for the management of data collection on physical activity.

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University of BRISTOL

Professor M.P. Furmston, TD, MA, BCL, LLM
School of Law
Wills Memorial Building
Queens Road
Bristol BS8 1RJ

Professor Christopher Riddoch
Department of Exercise & Health Sciences,
Centre for Sport, Exercise & Health
Tyndall Avenue
Bristol
BS8 1TP

2nd June2004

Dear Professor Riddoch,

Re: Calibration Studies

This is to confirm that the ALSPAC Law & Ethics Committee considered the calibration studies (Four Seasons Study and K4b2) on several occasions and have approved them.

Apart from some minor changes to the documentation they recommended that tokens for a 'Four Seasons Pizza' were not used as a reward for taking part in the study as this would be giving the wrong message. Tokens for activities (swimming, skating, bowling) were discussed but it was thought that these rewards might influence the results. The committee asked Dr Andy Ness to use 'neutral' rewards, e.g. C.D.s or cinema tickets.

With best wishes,

Professor Michael Furmston

Chair, ALSPAC Law and Ethics Committee

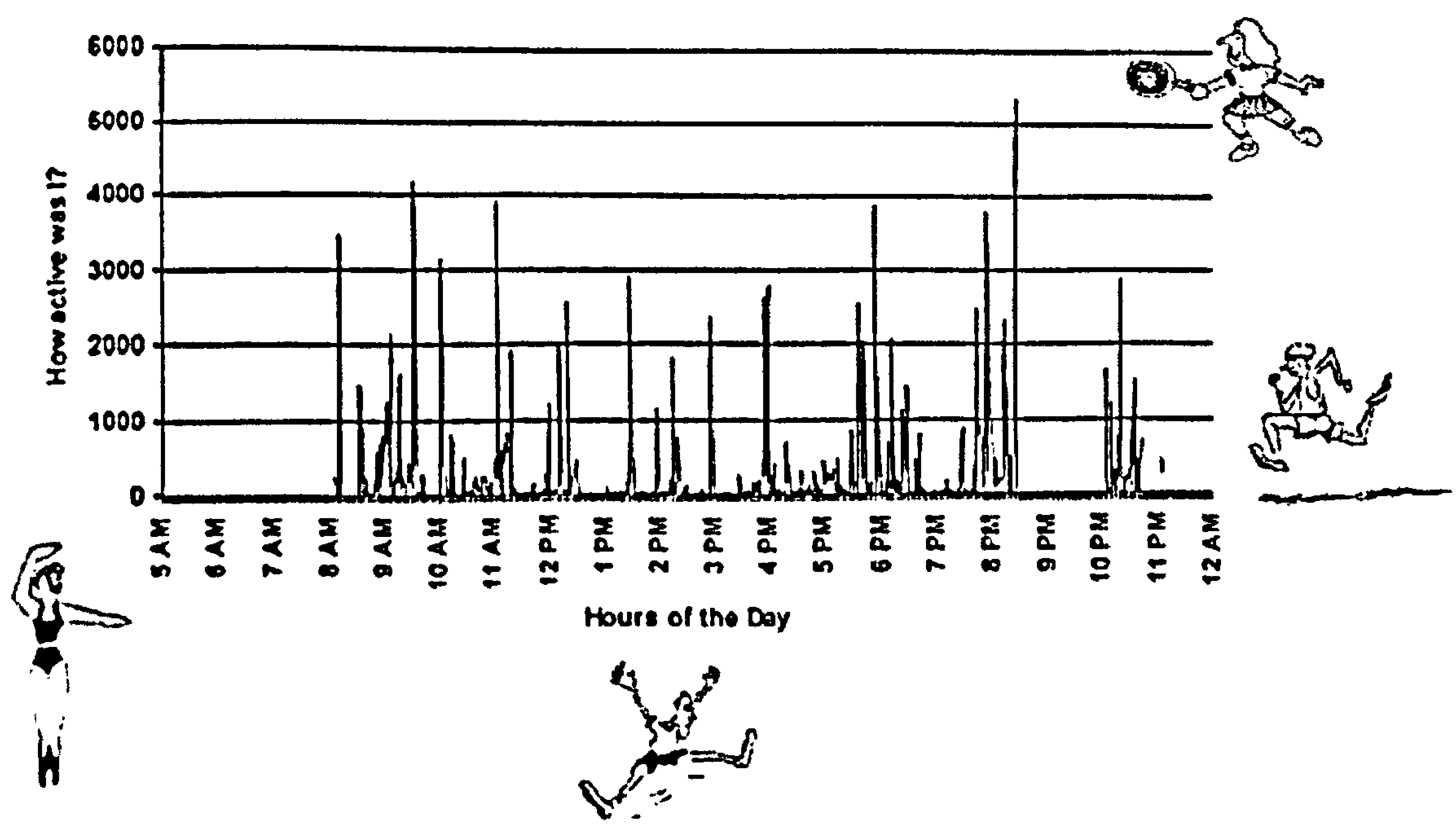
Focus 11+ Physical activity measurement for

The graph below shows how active you were on one day of the week you were wearing the Actigraph. It starts from the left - from 5 o'clock in the morning (when you were probably in bed!) until midnight. The higher the lines goes – the more active you were.

If you look for the first occasion when the lines are higher (in the morning) this is the time when you first picked up the Actigraph and put it on. Try to see if you can spot any peaks (high points) - you might be able to pick out when you went to school (especially if you walk to school), morning break (especially if you played outside), lunch break, PE lessons (if you had one), and the journey home. If you did anything active in the evening you should be able to see that as well.

If there are long sections of the graph where there are no peaks then this is when you were doing inactive things – such as sitting in class, watching TV, chatting with friends, etc. If the line is TOTALLY flat this is probably when you were not wearing the Actigraph (e.g. during the night).

What is interesting is to see how your activity changes throughout the day, depending on what you were doing. Looking at these patterns of activity is very useful to our research. Like most children, you will probably be more active on some days than others. This graph really only tells you how active you were on one day - you might be much more active or much less active on other days!



TIMESHEET

		Time Put ON	Time taken OFF	Reason for taking off	How much time spent: Swimming	How much time spent: Cycling
DAY 1	Time put on in morning →	1			Minutes	Minutes
Date		2				
		3				
	Time taken off at night	4 →				
DAY 2	Time put on in morning →	1			Minutes	Minutes
Date		2				
		3				
	Time taken off at night	4 →				
DAY 3	Time put on in morning →	1			Minutes	Minutes
Date		2				
		3				
	Time taken off at night	4 →				
DAY 4	Time put on in morning →	1			Minutes	Minutes
Date		2				
		3				
	Time taken off at night	4 →				
DAY 5	Time put on in morning →	1			Minutes	Minutes
Date		2				
		3				
	Time taken off at night	4 →				
DAY 6	Time put on in morning →	1			Minutes	Minutes
Date		2				
		3				
	Time taken off at night	4 →				
DAY 7	Time put on in morning →	1			Minutes	Minutes
Date		2				
		3				
	Time taken off at night	4 →				

Visit ID

Visit date

Date to send back

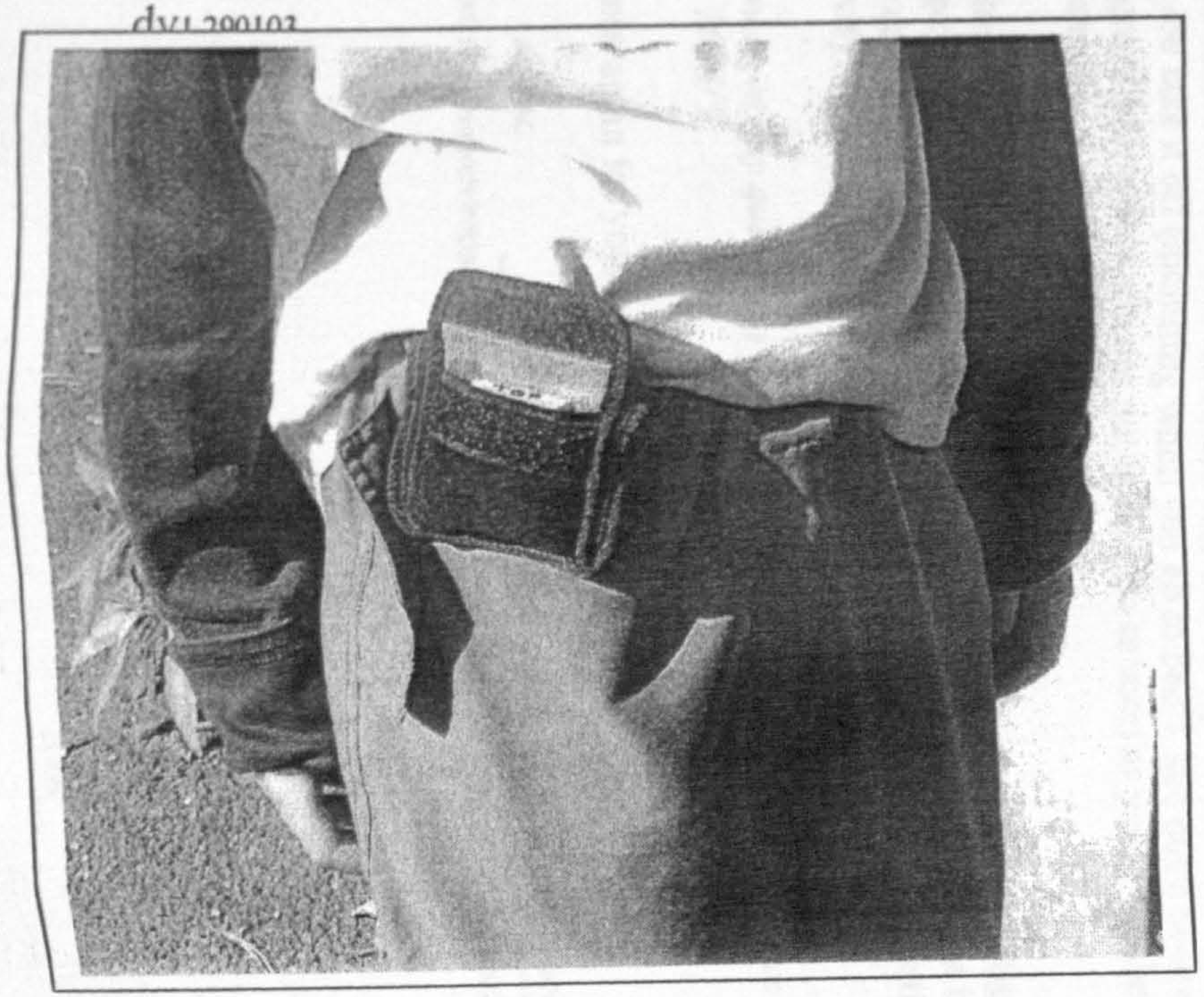
v1 29.01.03

Were these 7 days typical for you in terms of your usual activity? YES / NO (Please circle)

If NO, why not? (eg sprained ankle on day 3)

Instructions for wearing the Actigraph activity monitor

dv1 200103



- You should wear the Actigraph for 7 days, starting the morning after your visit to Teen Focus 2.
- Take off the Actigraph before you get into bed and record the time. It's a good idea to leave it somewhere you will easily see it first thing in the morning, like on top of your clothes.
- Remember to wear the Actigraph every day. **This is essential.**
- Every morning, remember to put the Actigraph on as soon as you wake up or immediately after having a shower or bath.
- The Actigraph can be worn underneath or on top of your clothing (unless you are wearing heavy clothing such as an anorak then it should go underneath). Adjust the belt so that the Actigraph is positioned just above the right hipbone (see photo opposite). Make sure Actigraph is the right way up, with the little notch at the top. The Actigraph must fit tightly but comfortably against your body. Adjust the strap to make a snug and comfortable fit.
- The Actigraph must not get wet. Try and cover it up in heavy rain. Please remove it for swimming, having a bath or shower. **Please remember to put in on again afterwards**. Record on the time sheet the periods when the Actigraph was not worn (see example below).
- The Actigraph is quite delicate. Please try not to drop it as it may break.
- At the end of the measurement period, please return the Actigraph and the time sheet in the envelope provided. **It is extremely important that the Actigraph is returned promptly.**

- **Any problems – please call the activity team on 0117 331 1638/9**

	TIMESHEET		Time put ON	Time taken OFF	Reason for taking off	How much time spent	
						Swimming	Cycling
Day 1	Time put on in morning →	1	7.30 am	11.00 am	Went swimming	Minutes	Minutes
Date	22/01/03	2	12.00 pm			60	20
		3					
	Time taken off at night →	4	→	9.30 pm	Went to bed		

Appendix 9

CHILDREN OF THE 90s

Focus11+

24 Tyndall Avenue
Bristol BS8 1TQ
(correspondence only)
Tel: 0117 928 8266 There is an answerphone on this line.
e-mail: focus-admin@bristol.ac.uk

Dear Study Child,

Focus11+ Physical Activity Study

Thank you for agreeing to take part in the Children of the 90's Physical Activity Study.
At your Focus11+ visit you will have been given a Physical Activity pack. This contains:
an **Actigraph Physical Activity monitor** for you to wear for 7 days. This will record all of your movements.
an **instruction sheet** showing you how to use the Actigraph correctly.
a **time sheet** on which you should record all the times you put the Actigraph on and take it off.
A **postcard** for you to carry with you at school to explain to your teacher that you are taking part in this important study.
a **pre-paid envelope** for you to post the Actigraph and timesheet back to us as soon as the seven days is up.

The Actigraph is a little plastic box that you should wear tightly around your waist, as you were shown at your Focus11+ visit. The Actigraph will measure your physical activity by recording all of your movements. *You should try to wear the Actigraph every day for seven days starting the day after your Focus11+ visit.* Please put it on first thing in the morning and wear it until you go to bed. Remember to leave it somewhere at night where you will spot it the next morning! The Actigraph will not affect what you do normally, so please behave just the same.

Please record on the time sheet, the time you first put the Actigraph on in the morning and any times that you take it off (including when you go to bed!), and put it back on. If you forget to wear the Actigraph at any time, please put it back on as soon as you remember, and record the time on the timesheet.

At the end of the seven-day period, don't forget to post the Actigraph and timesheet back to us in the pre-paid envelope provided! It is important that we receive it back as soon as possible. When we receive the Actigraph back from you, we can send you a certificate with a graph of your activity!

If you have any queries or problems you (or your parent/carer) can telephone the activity team on 0117 331 1638/9

Thanks again for your help!

V1 29.01.03

CHILDREN OF THE 90s

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Tel: 0117 928 8266 There is an answerphone on this line.
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Dear Parent/Carer,

Focus11+ Physical Activity Study

At your Focus11+ visit you will have been given a Physical Activity pack. This contains an Actigraph Physical Activity monitor, a card to take to school, an instruction sheet, a time sheet and a pre-paid envelope to post the Actigraph and timesheet back to us.

The Actigraph is a little plastic box that is worn around the waist. It is designed to measure physical activity by measuring and recording all of your child's movements. *Your child should try to wear the Actigraph every day for seven days starting the day after your Focus11+ visit.* She/he should put it on first thing in the morning and wear it until they go to bed. It is important that the Actigraph is fastened tightly to the body and has no free movement. The Actigraph does not interfere with daily life – we would like your child to behave just as they would do normally.

Please ensure your child records on the time sheet, the time they first put the Actigraph on in the morning and any times that they take it off (including when they go to bed), and put it back on. If they forget to wear the Actigraph at any time, please remind them to put it back on as soon as they remember and record the time on the timesheet.

At the end of the seven-day period, we would be most grateful if you could post the Actigraph and timesheet back to us in the pre-paid envelope provided. It is important that we receive it back as soon as possible and we will send your child a certificate with a graph showing his/her activity.

It is expected that we will gain valuable information from this study that will improve our understanding of the activity habits of 11/12 year-old children. We also hope to use this information in relation to their body size, physical fitness, lung function and the activity diary they may have completed last year. There are no discernible risks for taking part in this study. Actigraphs are completely safe to use.

If you have any queries or problems you can telephone the activity team on 0117 331 1638/9

Many thanks for your help.

ALSPAC Avon Longitudinal Study of Parents and Children CHILDREN OF THE 90s

ALSPAC is a research initiative of the Unit of Paediatric & Perinatal Epidemiology, Institute of Child Health, University of Bristol

Appendix 10

Name:

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is a study child in the 'Children of the 90's' project, and is wearing an activity monitor on his/her hip for 7 days for research purposes. The monitor should be worn at all times, except for those activities that will get it wet, i.e. swimming, bathing and showering. Thank you for your co-operation.

Jean Golding

Professor Jean Golding
Study Director